Single-mode Quantum Cascade Lasers Emitting at 3.3 µm

R. Teissier, J. Devenson, O. Cathabard, and A.N. Baranov

Institut d'Électronique du Sud

Université Montpellier 2 / CNRS

Montpellier, FRANCE

UNIVERSITÉ MONTPELLIER 2
SCIENCES ET TECHNIQUES

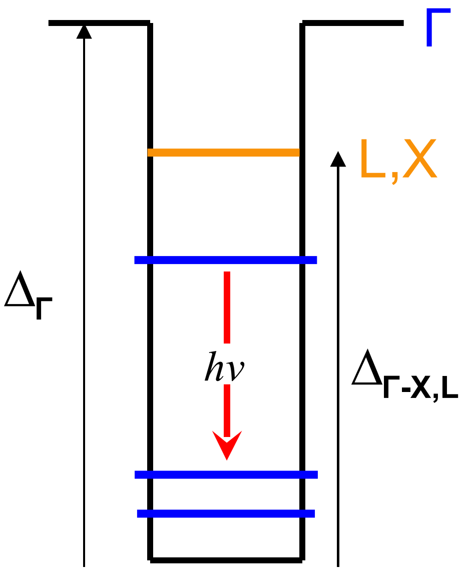
Motivations

- Explore one frontier of QCL spectrum
- Provide lasers for gas sensing
  in the 3 – 4 µm wavelength range

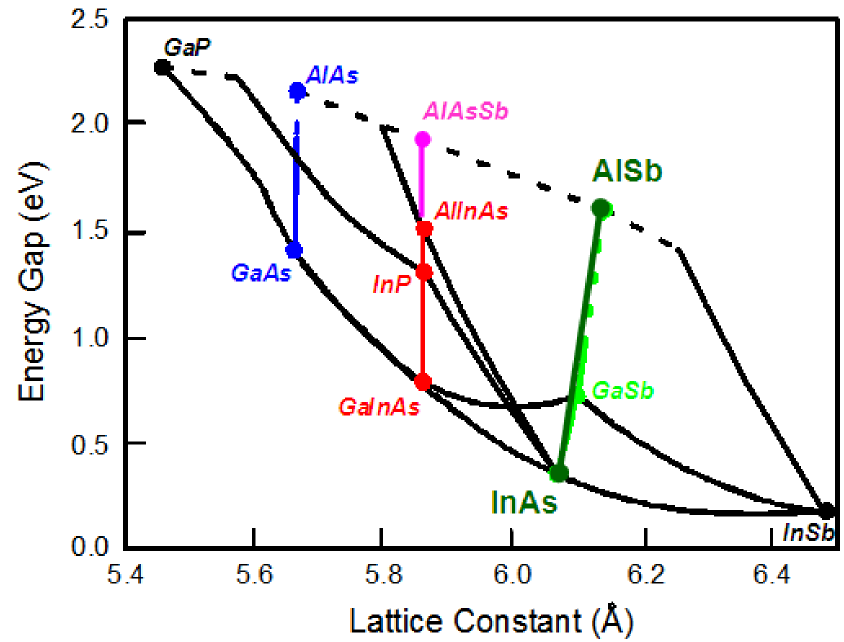
Outline

- Design and fabrication
- FP lasers
- DFB lasers
- Short wavelength QCL limit

Antimonides : best materials for short λ QCLs

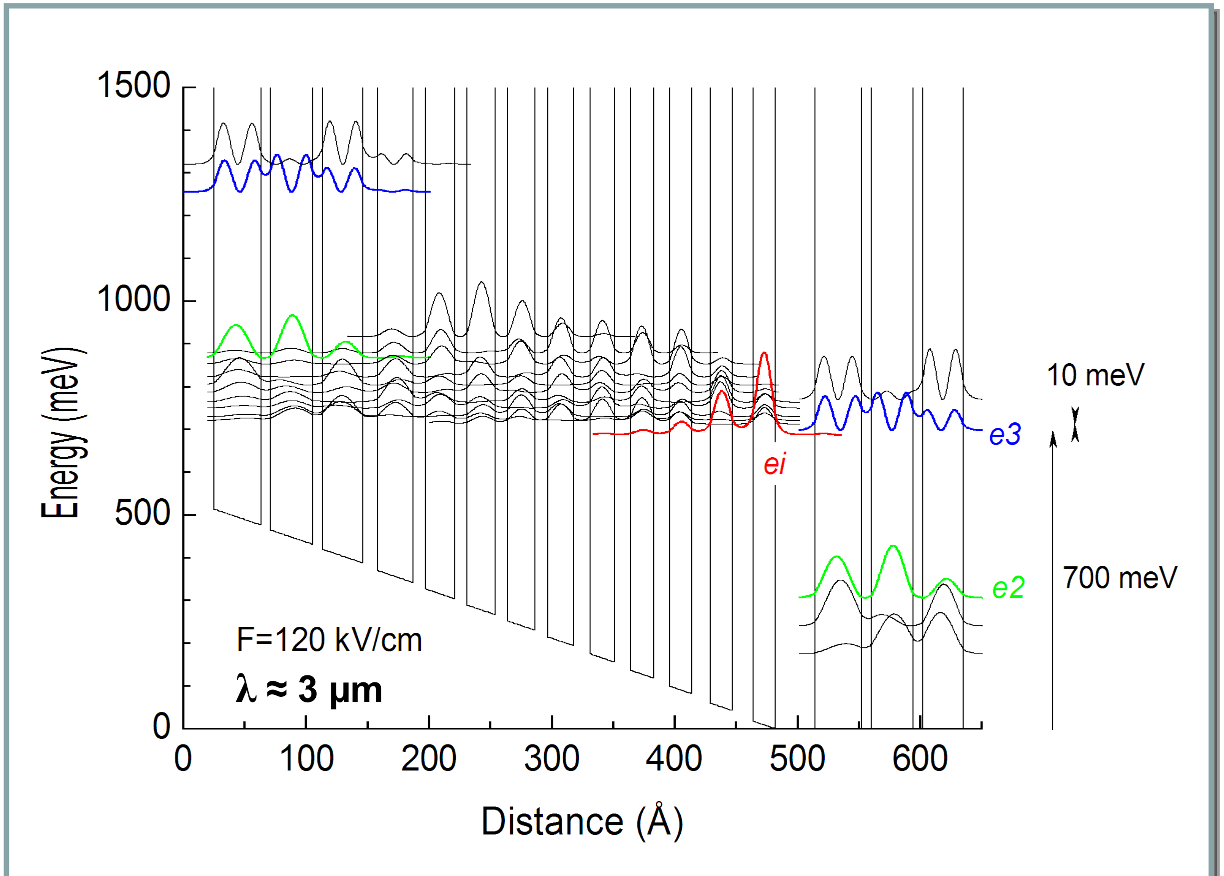


high Δ_Γ
+
high $\Delta_{\Gamma\text{-X,L}}$
+
low m*



	GaAs/ AlGaAs	InGaAs/ AlInAs	Strained InGaAs/ AlInAs	InGaAs/ AlAsSb	**InAs/ AlSb**	ZnCdSe/ ZnCdMgSe	GaN/ AlN
Δ_Γ (eV)	0.35	0.5	0.74	1.6	**2.1**	0.78	2
$\Delta_{\Gamma\text{-X,L}}$ (eV)	0.35	0.53	0.61	0.5	**0.73**	>1.2	1.6
m*	0.067	0.043	0.035	0.043	**0.023**	0.128	0.2

InAs/AlSb QCL vertical design



High energy levels

$h\nu$ ~ 400 meV

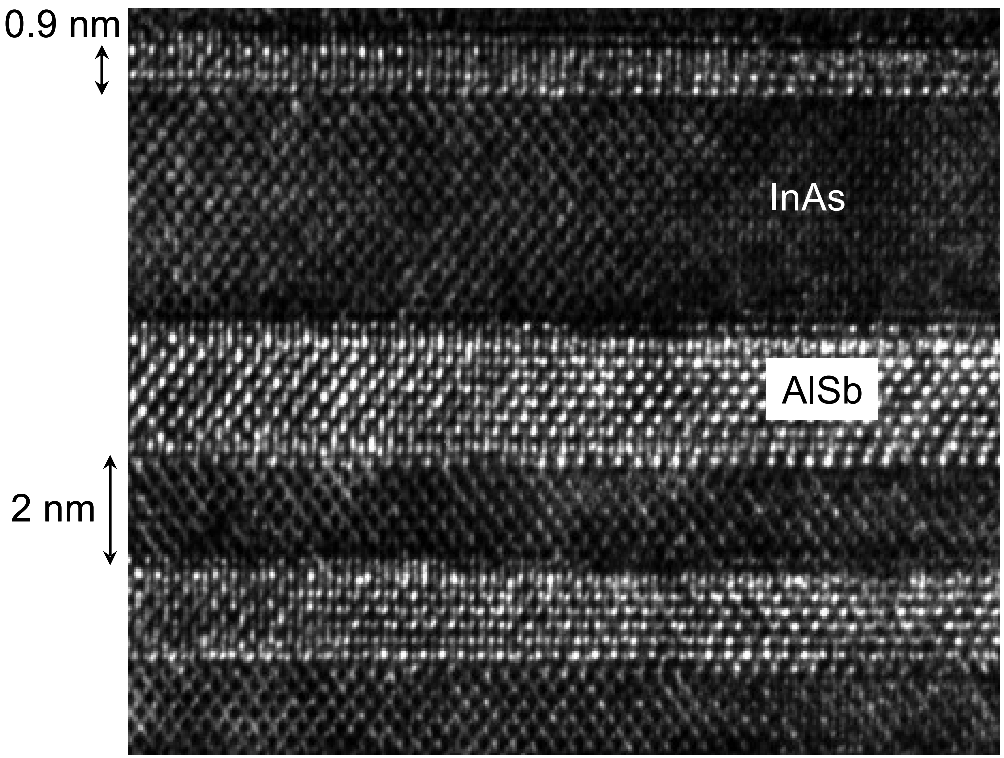
e3 ~ 700 meV

Very thin layers

Large number of QWs

High accuracy is required in modeling and growth

Heterostructure growth by Molecular Beam Epitaxy



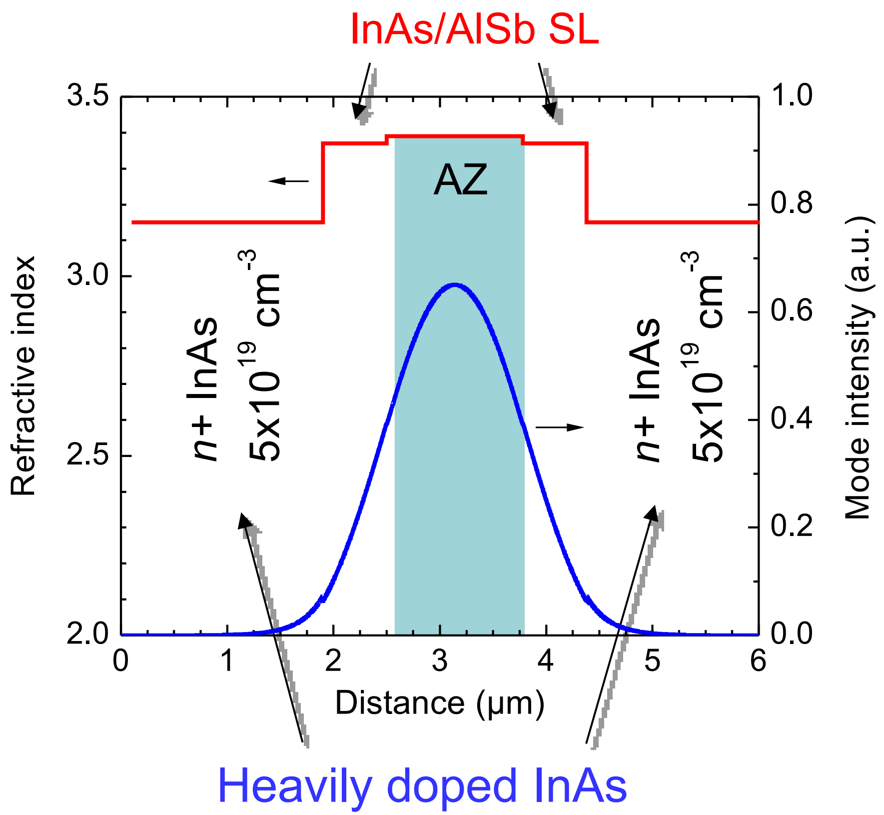
TEM image : Anne Ponchet, CEMES, Toulouse

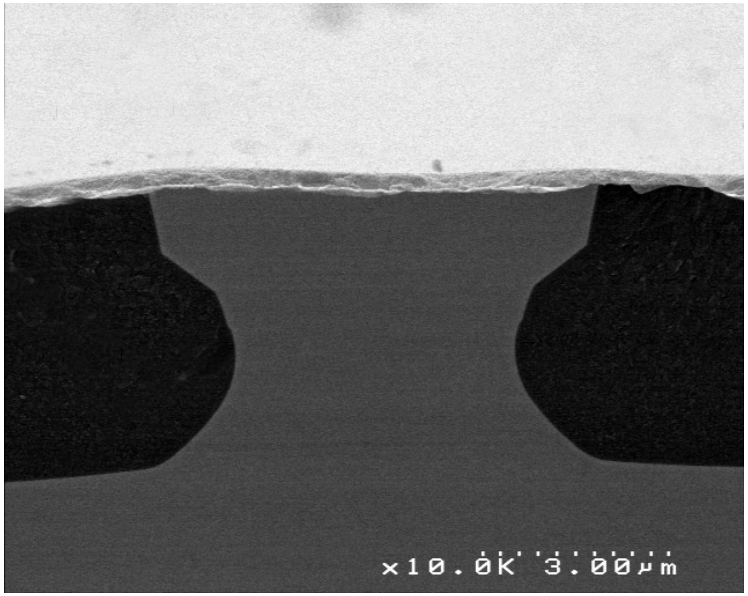
Abrupt InAs / AlSb interfaces (<1 ML)

Strain control through AlAs-like interface bonds

Reproducible, high quality, material growth

InAs-based waveguide



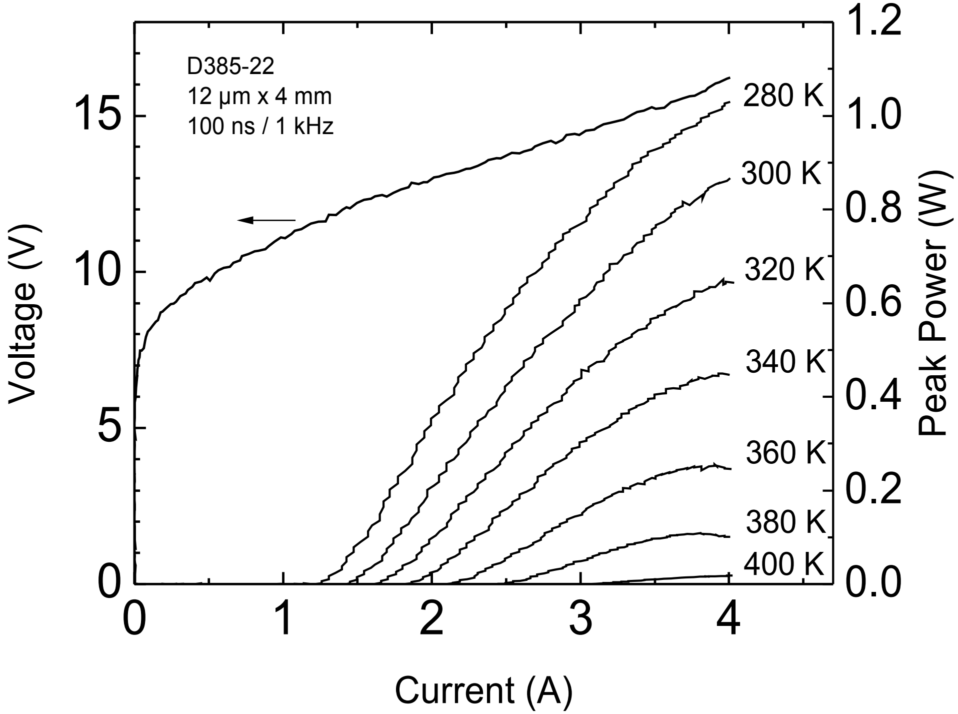


- transparent due to Moss-Burstein effect
- low refractive index
- acceptable free carrier absorption

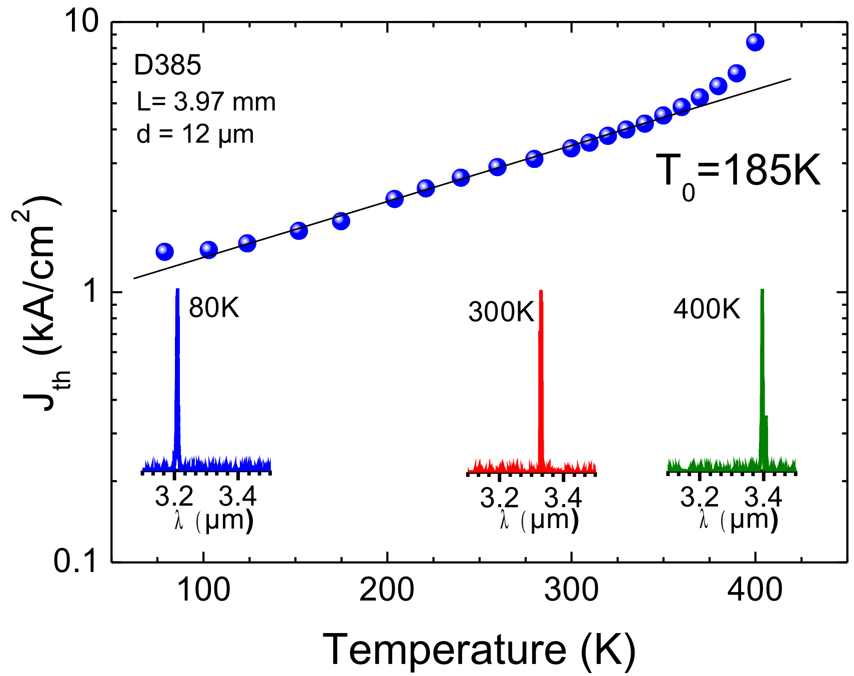
$\Gamma = 0.6, \quad \alpha_w = 6\ cm^{-1}$

Wet etched ridge, 5 - 20 µm wide
HR coated back facet (SiO_2/Au)
Indium soldered epi-side down

InAs/AlSb QCLs emitting near 3.3 µm



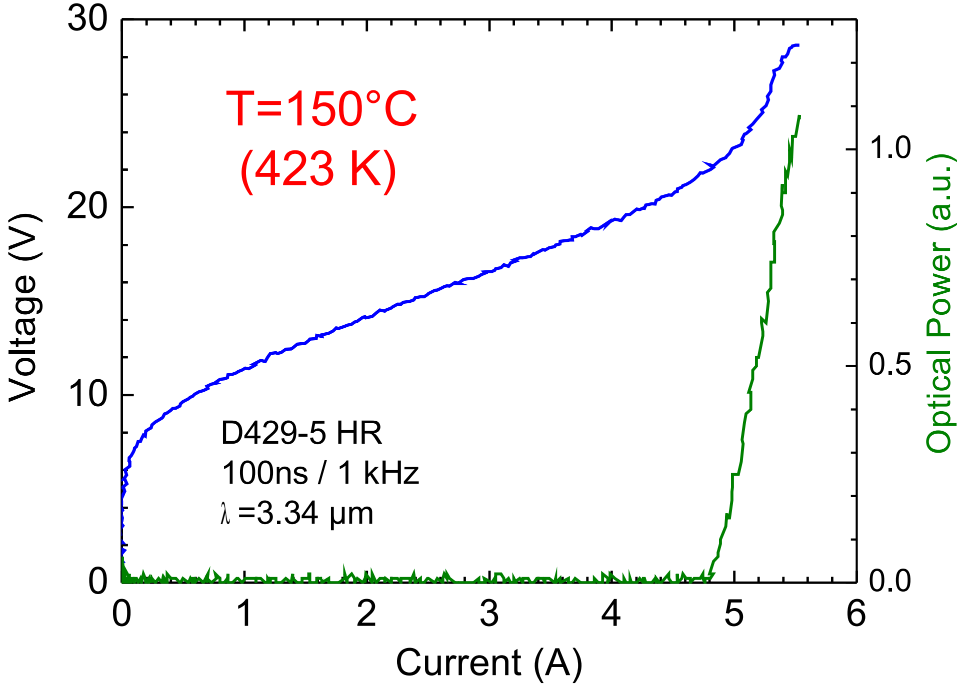
T_{max} > 400 K

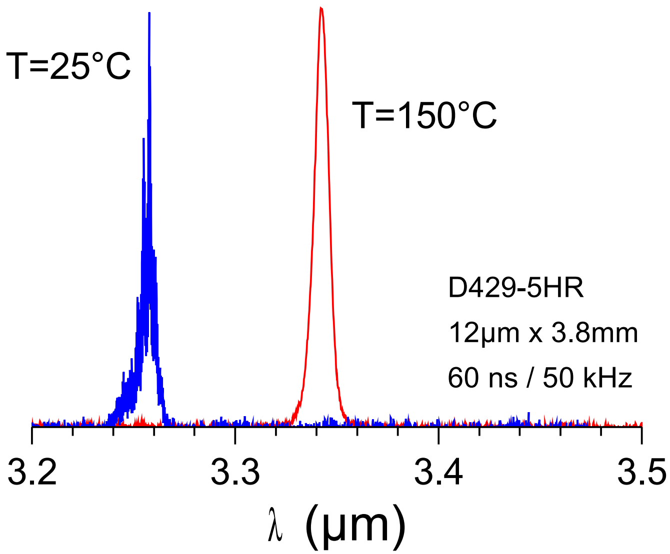


at room temperature:

λ= 3.33 µm, J_{th}=3.0 kA/cm^2, P ~ 1 W

High temperature operation





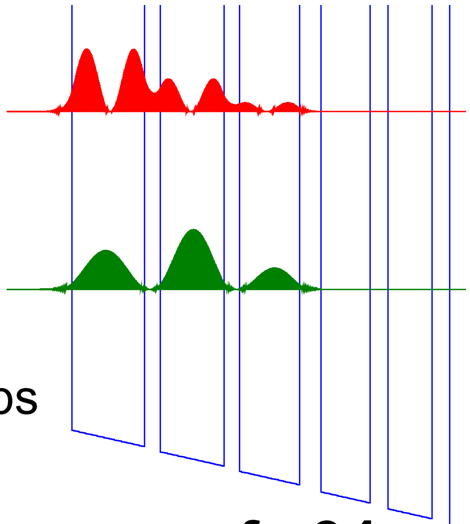
25°C **λ = 3.25 μm**

150°C **λ = 3.34 μm**

advantage over interband lasers

Diagonal design

Vertical design with strong wavefunction overlap



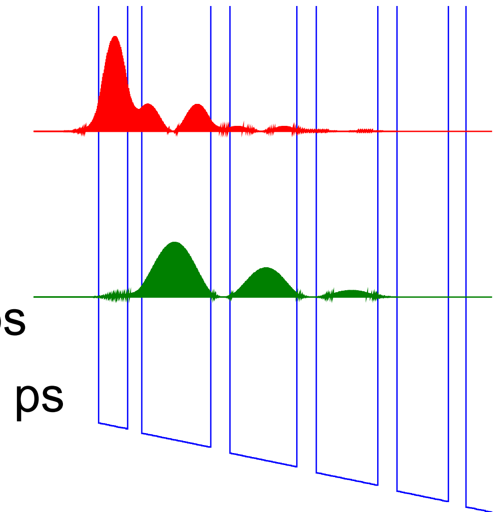
f=38

τ_{up}=1.2 ps

τ_{low}=0.29 ps

$$G_{VERT} \sim (\tau_{up}-\tau_{low}).f = 34$$

Diagonal design with longer upper state lifetime



f=20

τ_{up}=2.4 ps

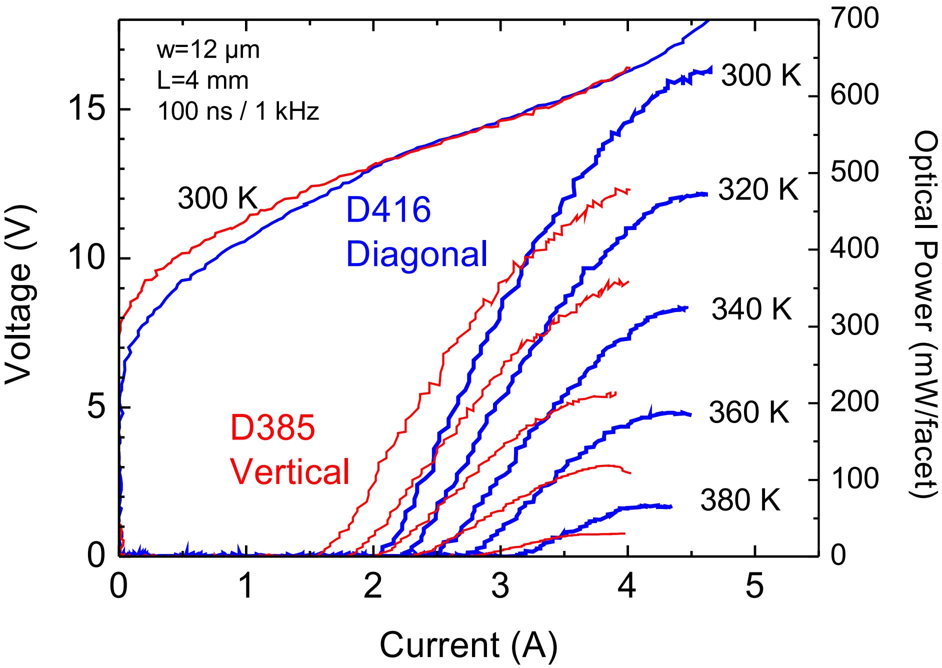
τ_{low}=0.26 ps

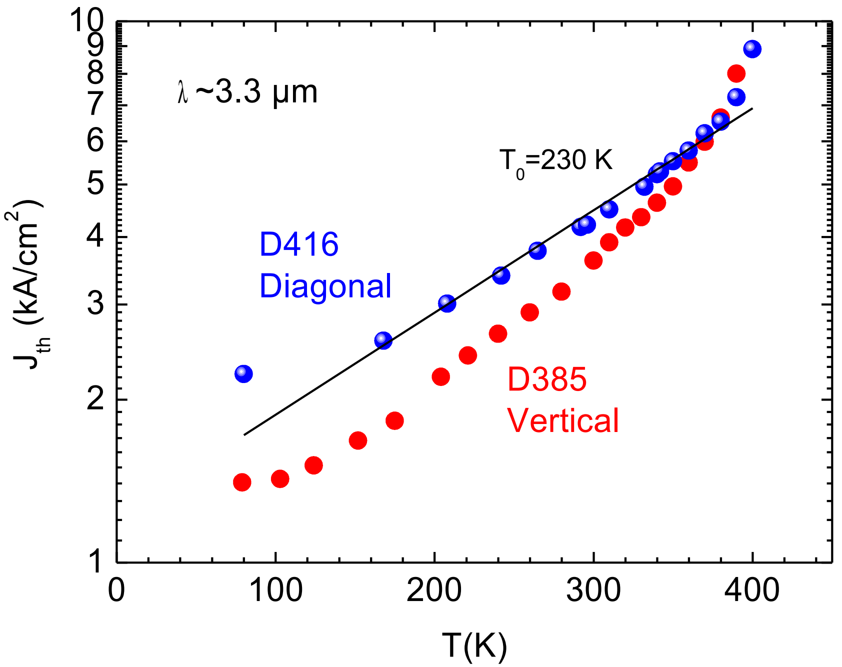
$$G_{DIAG} \sim (\tau_{up}-\tau_{low}).f = 43$$

Higher gain
Less sensistive to lower state population

Lower threshold
Better slope efficiency

Diagonal vs. Vertical designs





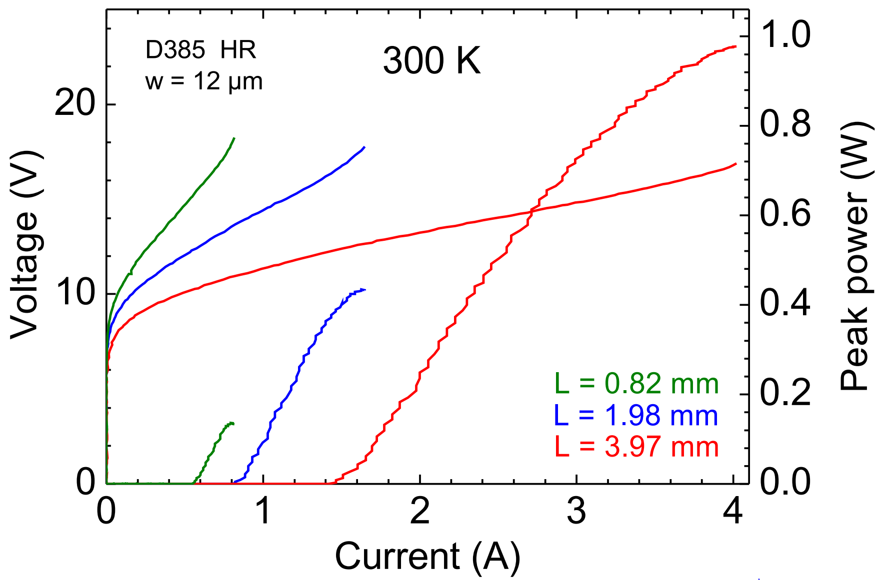
Better efficiency at high T and high currents

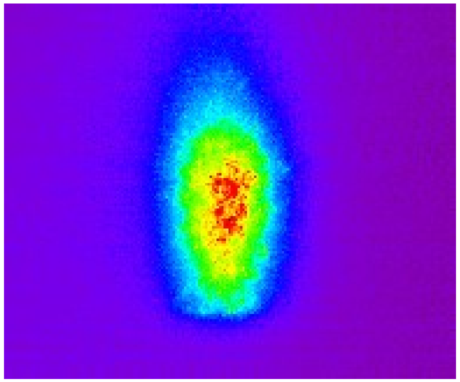
But threshold is larger than expected

Additional non radiative scattering? Interfaces?

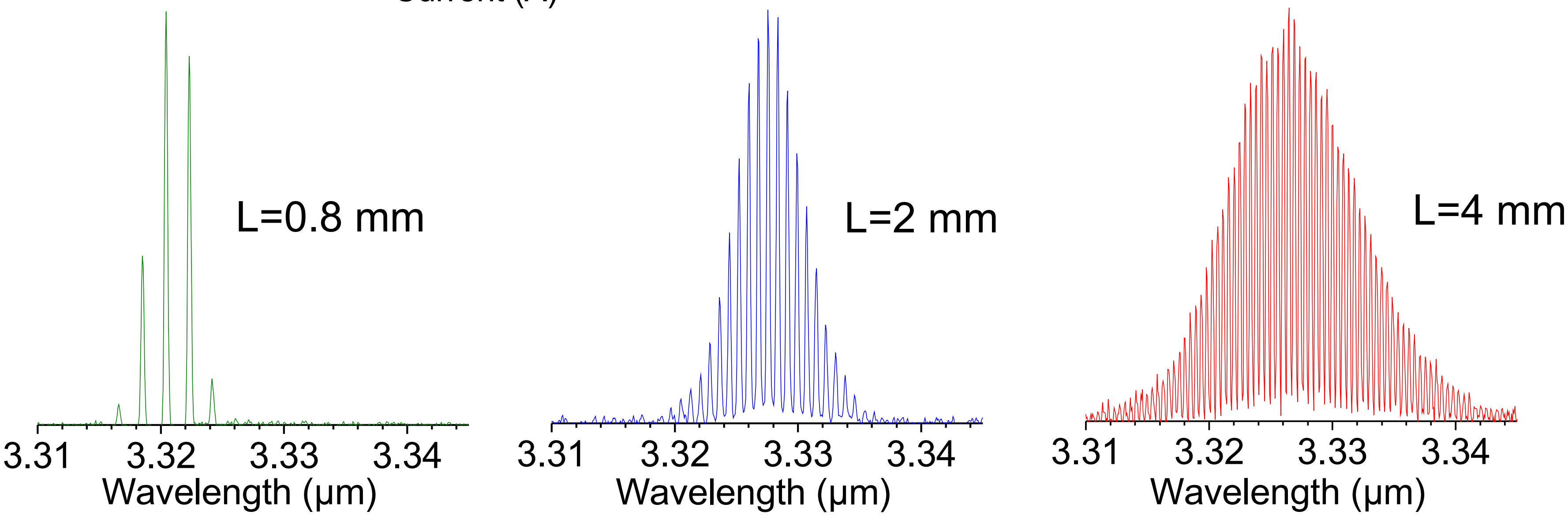
$$\frac{1}{\tau_{up}} = \frac{1}{\tau_{ph}} + \frac{1}{\tau_i} \qquad \tau_i \approx 0.6\ ps$$

Fabry-Pérot emission spectra



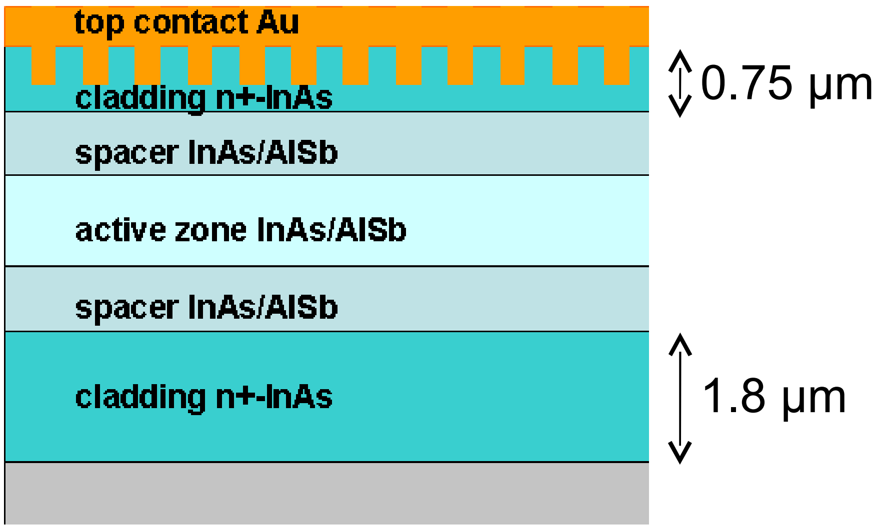


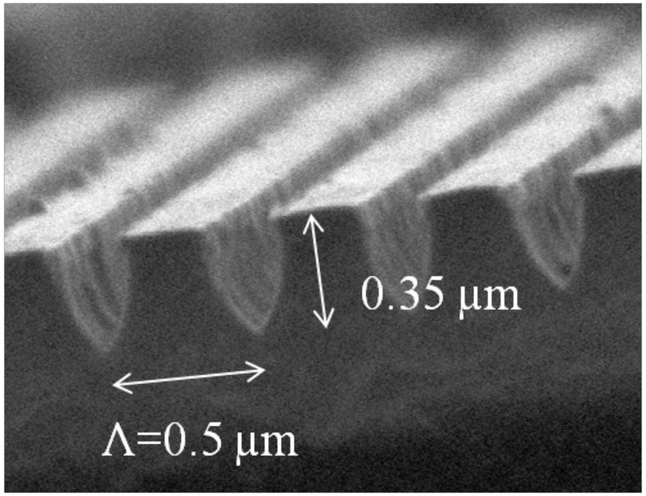
Single lateral mode

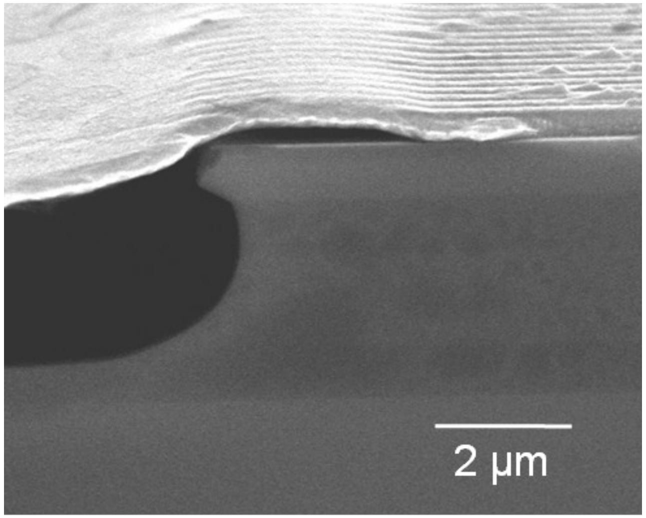


DFB lasers

Holographic lithography
ICP etched grating
Wet etched ridge



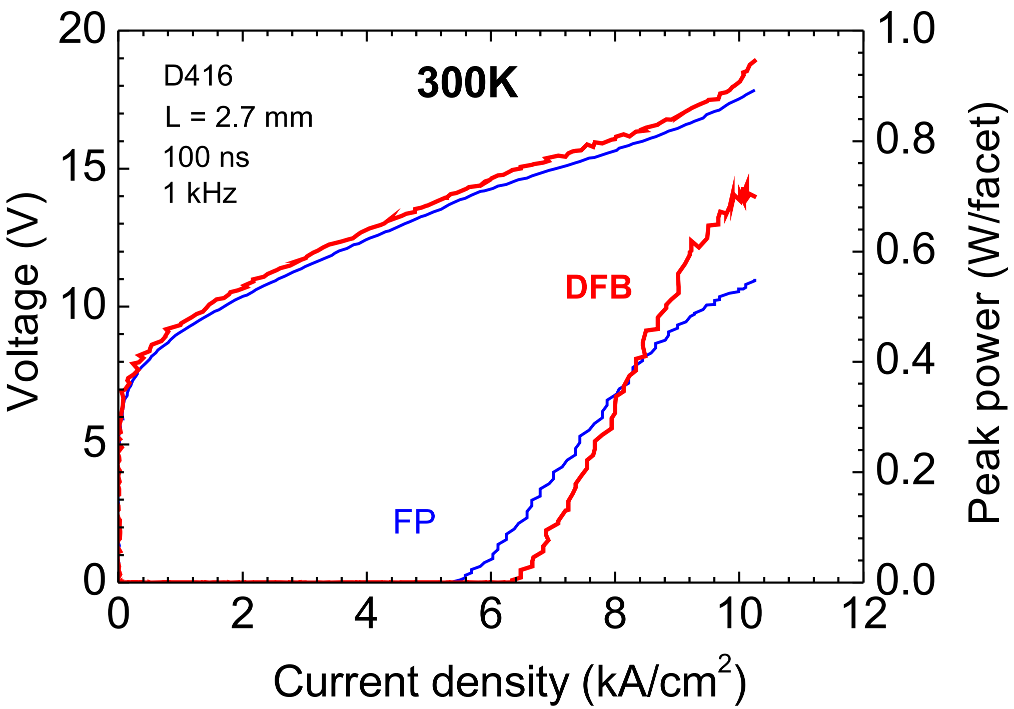


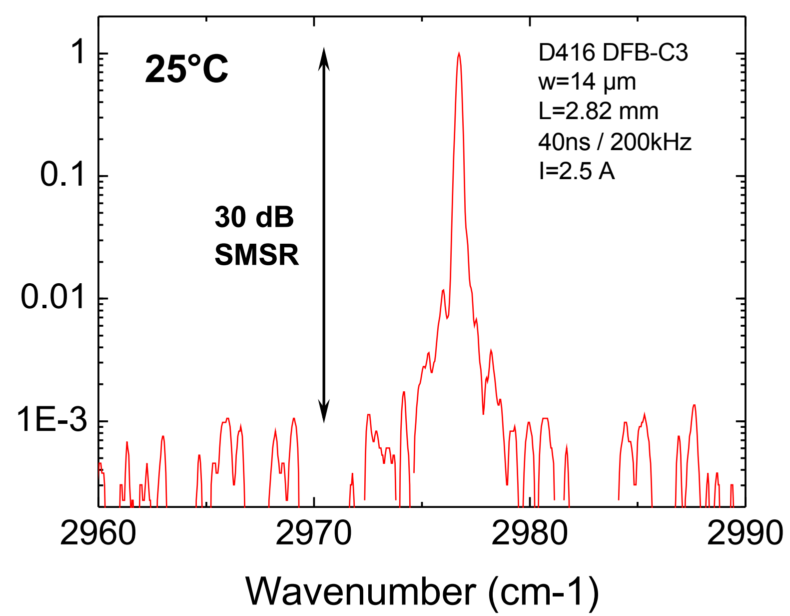


κ =12 cm⁻¹

dominated by index coupling

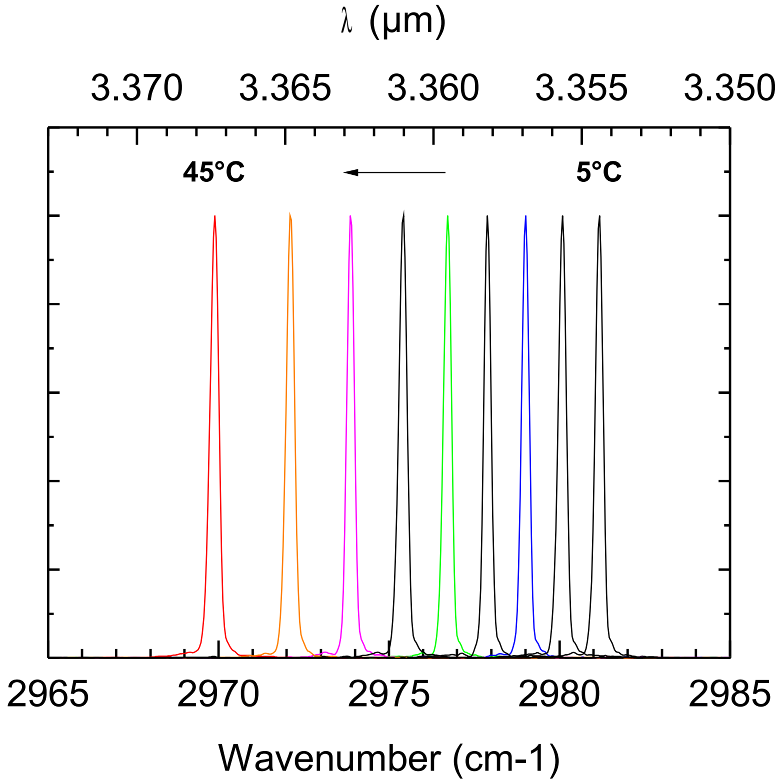
DFB QCL emitting near 3.3 µm

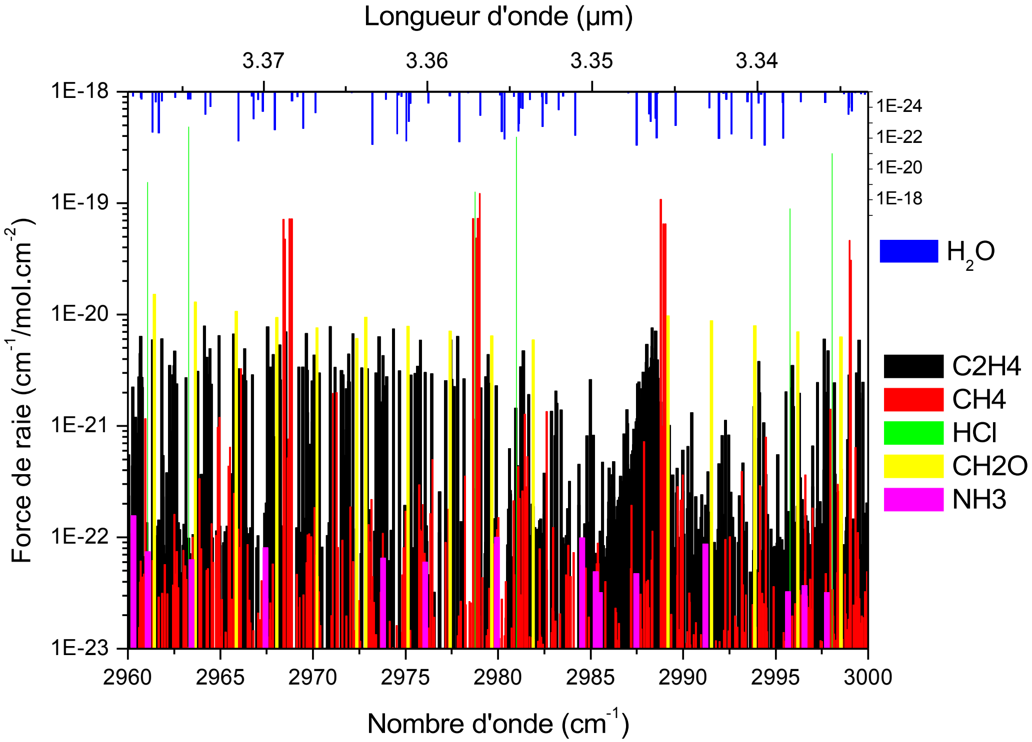




High peak power single mode emission
at Room Temperature

Tuning range





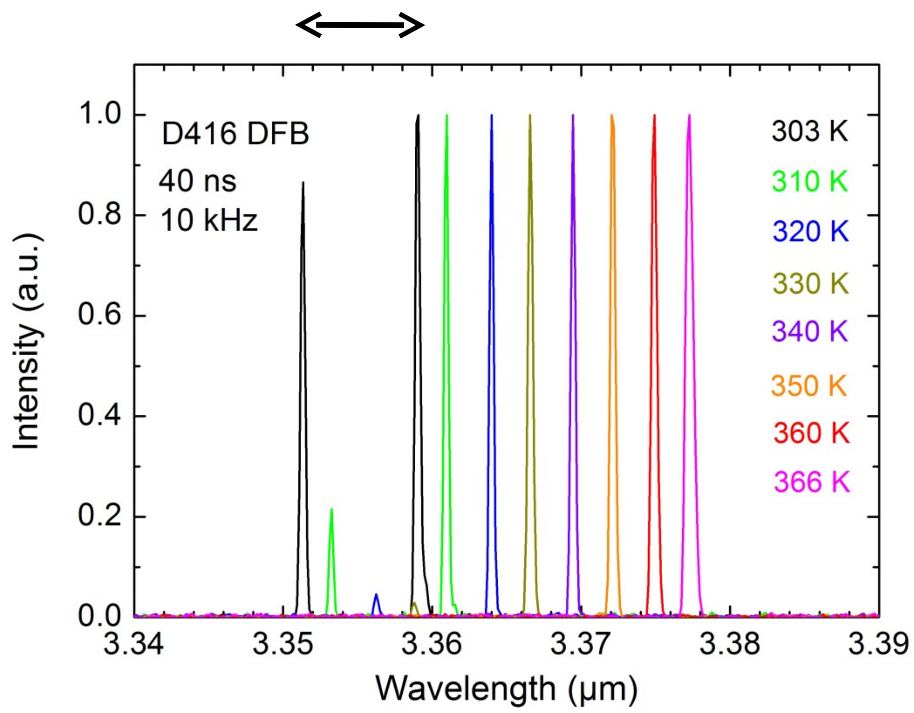
HITRAN

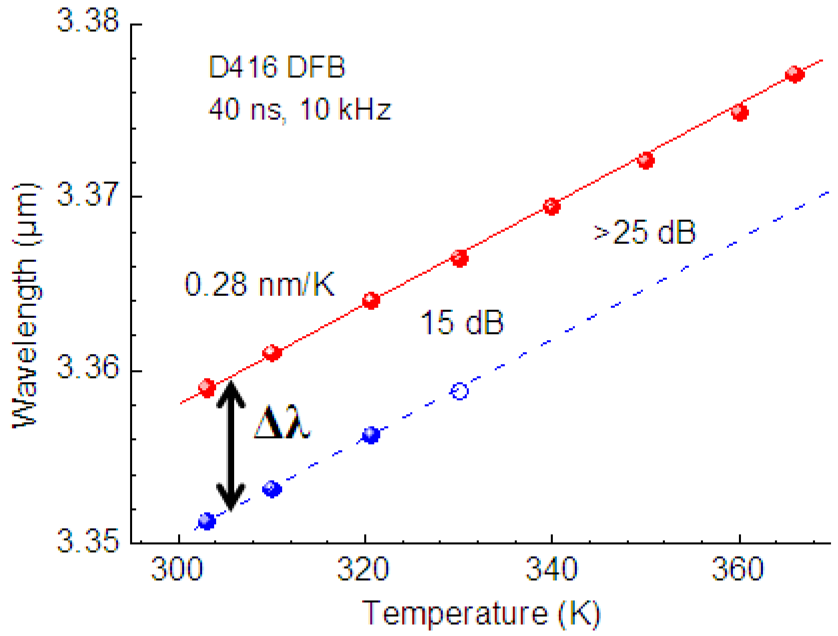
tuning rate ~ 0.3 cm^{-1}/K

> 10 cm^{-1} tuning range, SMSR > 30 dB

DFB coupling

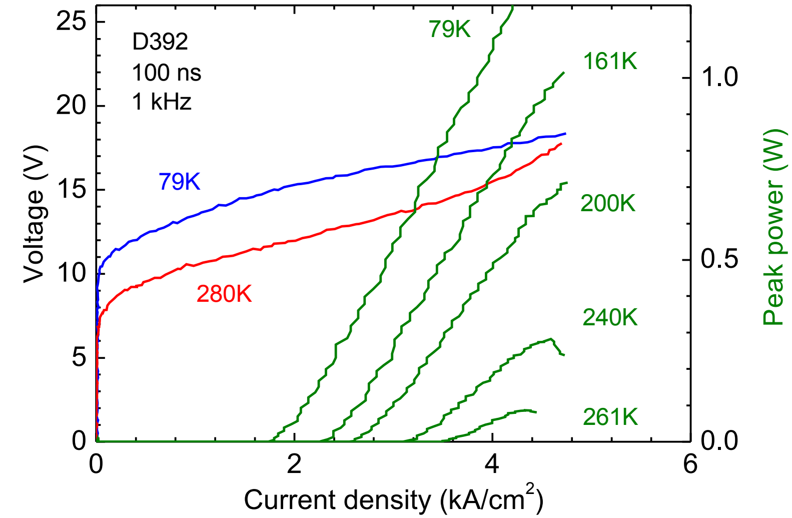
stop band
$\Delta\lambda$=7.8 nm   =>   over-coupling ($\kappa L >> 1$)

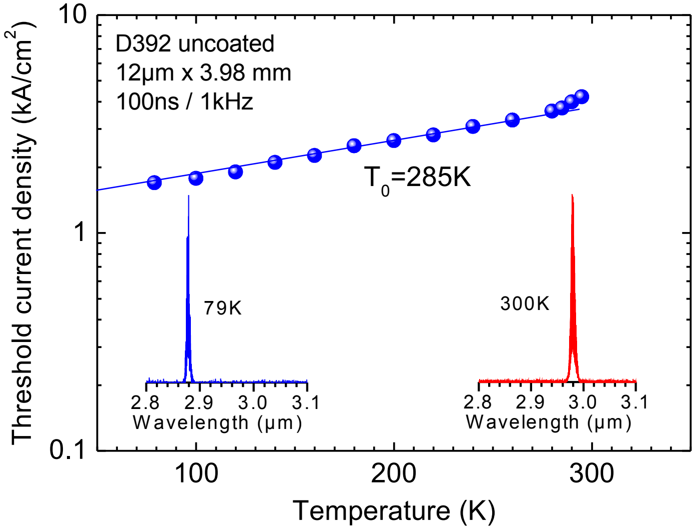




Single frequency operation between 60 and 95°C

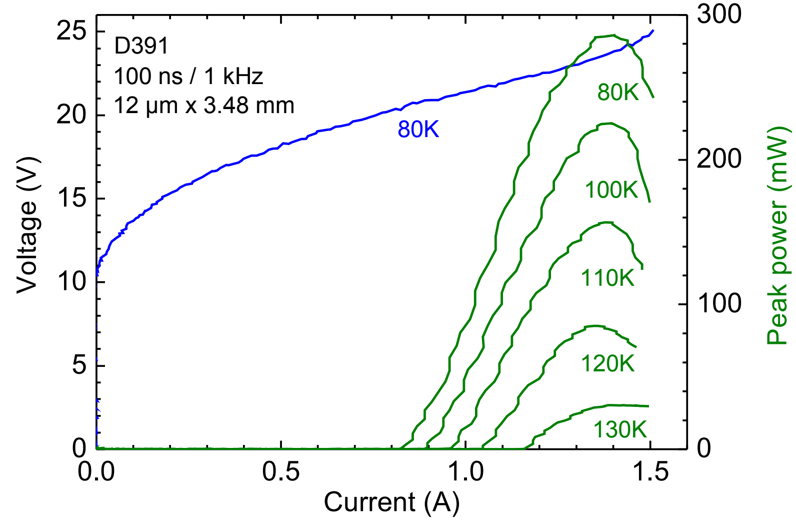
Short wavelength limit





shortest room temperature operation

λ= 2.98 µm, (J_{th} ≈ 4.5 kA/cm²)

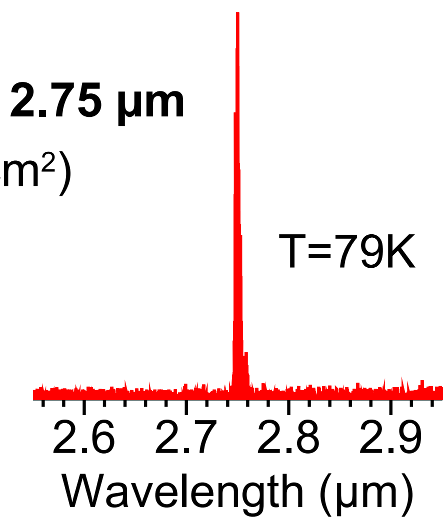


QCL emission at λ = 2.75 µm

Low J_{th} (< 3 kA/cm²)

higher T operation

limited by early NDR



Summary

Antimonides prove their high potential for short wavelength QCLs

High peak power, high temperature operation of FP lasers in the 3-4 µm range

Tunable single frequency operation of DFB lasers at 3.35 µm, with high peak power at room temperature

Perspectives

Cover the whole range from 3 to 4 µm with DFB QCLs

Improve performances (higher DC)

Applications in gas sensing systems