High quantum-efficiency GaInAs/Al(Ga)AsSb quantum cascade lasers for the 3-5 μm wavelength range

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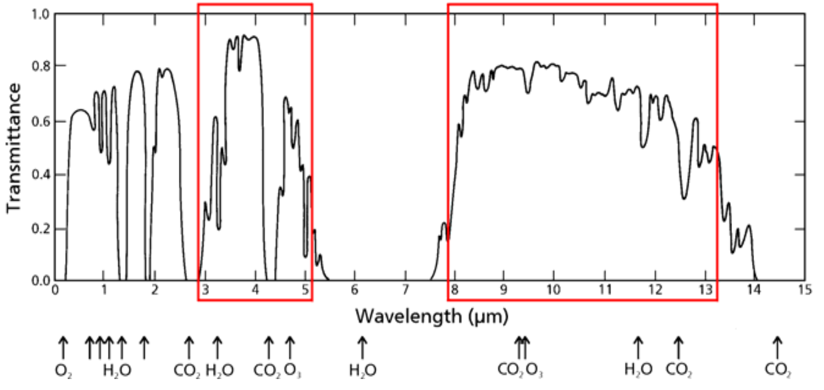
Motivation: high-power high-efficiency λ ~ 3 - 5 µm QC lasers



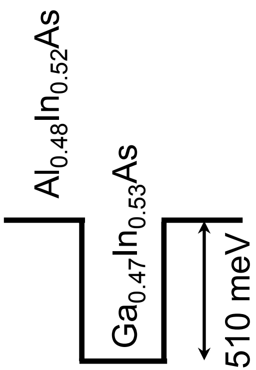
- For a variety of applications, such as remote sensing and infrared countermeasures, high-power high-efficiency QC lasers are required
- High-power lasers with λ < 5µm still challenging for QC lasers

Outline:

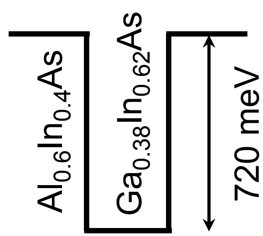
- QC lasers for 3-5 µm: Material systems
- Growth and processing
- To achieve high quantum-efficiency QC lasers at λ ~ 3.7-3.9 µm
  - GaInAs/AlAsSb QC lasers emitting at λ **~** 4.5 µm
  - λ **~ 3.7-3.9 µm** GaInAs/AlAsSb QC lasers based on 3-QW active region
  - High peak power **(10 W)** GaInAs/AlGaAsSb QC lasers
- Summary

Material Systems with Large Conduction Band Discontinuity

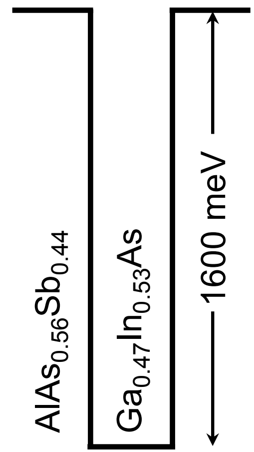
InP substrate
$Ga_{0.47}In_{0.53}As$ / $Al_{0.48}In_{0.52}As$
(lattice-matched)



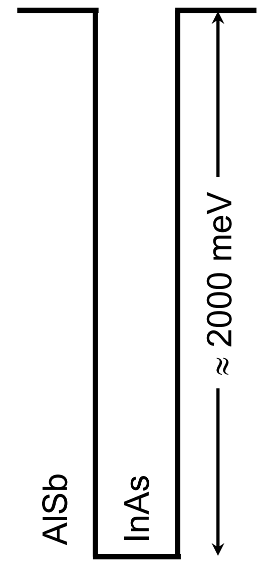
InP substrate
$Ga_{0.38}In_{0.62}As$ / $Al_{0.6}In_{0.4}As$
(strain-comp.)



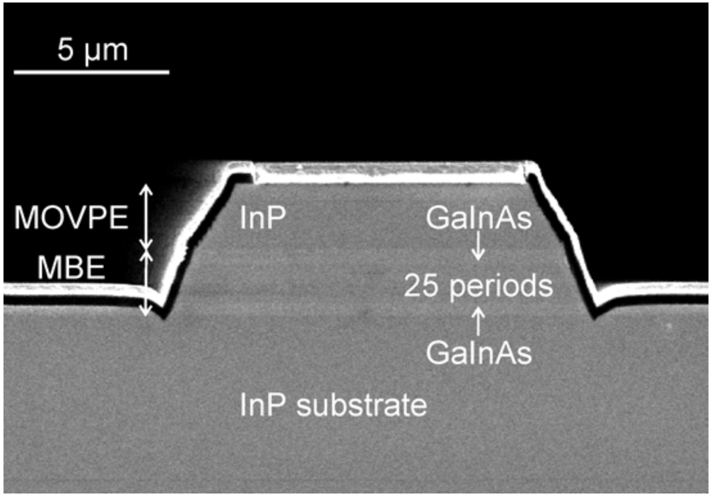
InP substrate
$Ga_{0.47}In_{0.53}As$ / $AlAs_{0.56}Sb_{0.44}$
(lattice-matched)

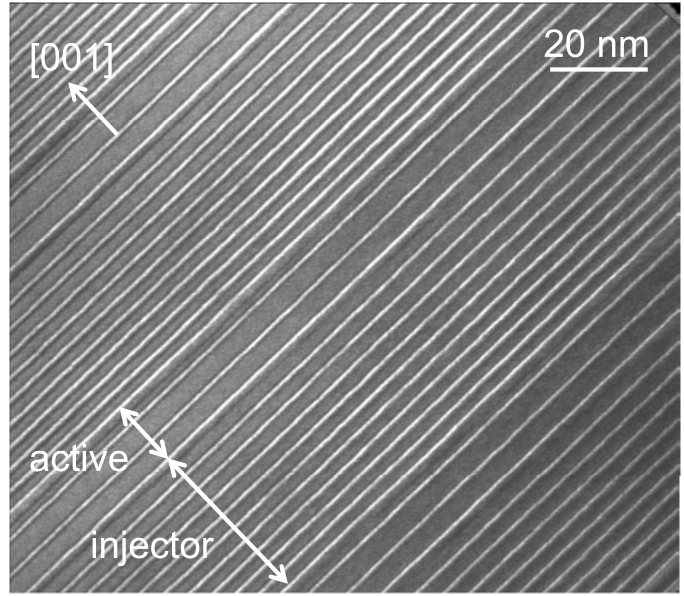


InAs substrate
InAs / AlSb



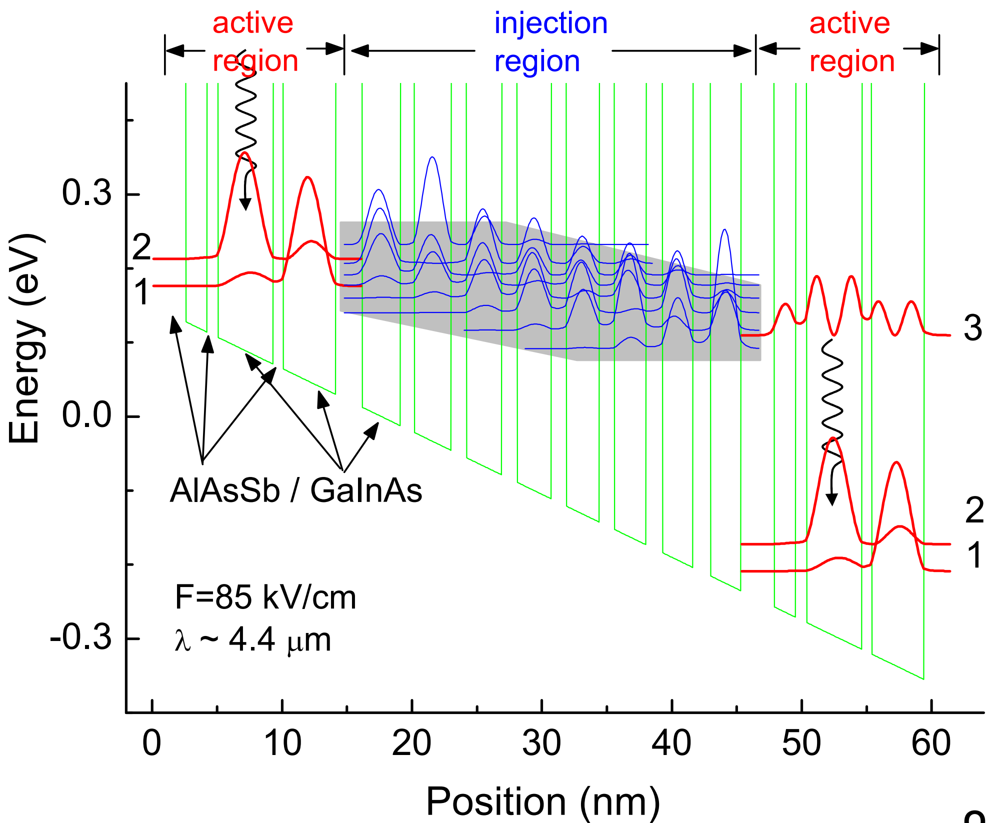
Fabrication of Quantum Cascade Lasers at Fraunhofer IAF





- 2" wafer technology
  - MBE: active regions and separate confinement layers ≈ 2.7 µm
  - MOVPE: overgrowth of InP cladding and contact layers ≈ 3.0 µm
  - processing into mesa-waveguide structures (edge-emitters) w = 7 – 34 µm
  - cleavage, facet coating, mounting, etc. L = 1 – 3 mm

Above RT GaInAs/AlAsSb QC lasers: Design



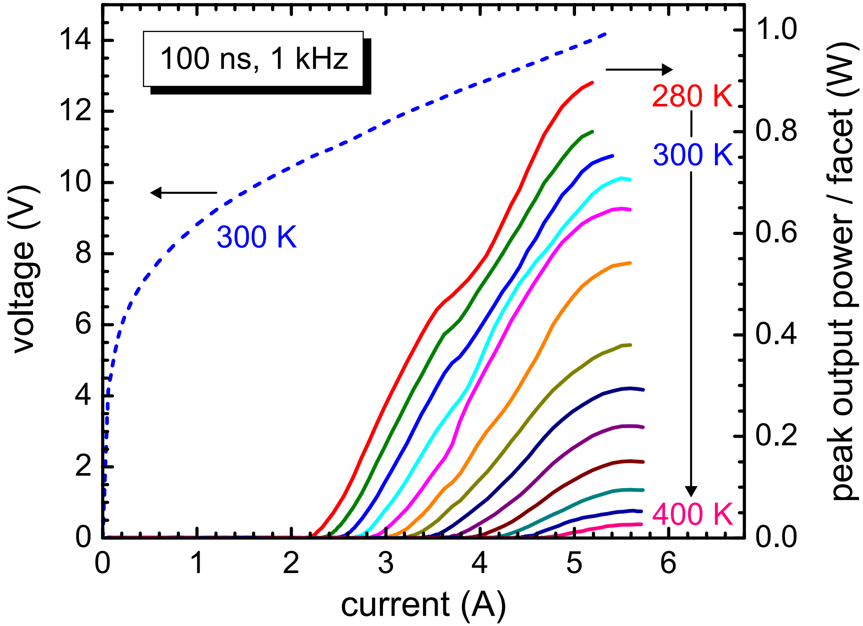
Triple-well active region;

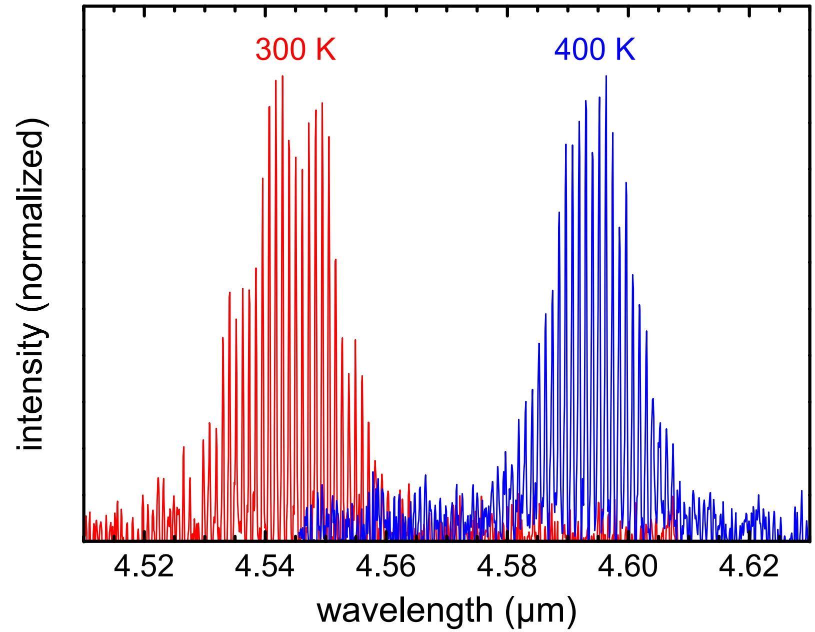
Vertical transition;

$\lambda \sim 4.4\ \mu m$

Q. Yang et al., Appl. Phys. Lett. 86, 131107 (2005).

GaInAs/AlAsSb QC lasers operating up to 400 K





device: 18 x 2800 µm²
uncoated
100 ns / 1 kHz

- **max. pulsed operating temperature: >400 K (>127 °C)**
- **emission wavelength @ 300 K: 4.54 µm**

Q. Yang et al., Appl. Phys. Lett. 86, 131107 (2005)

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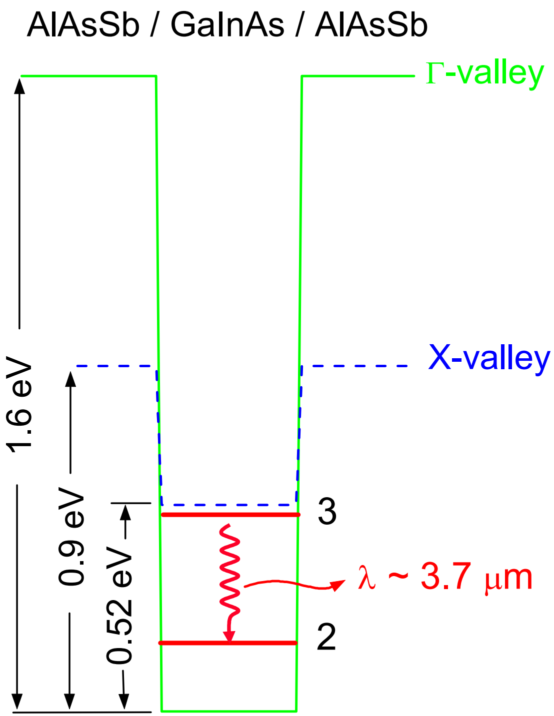
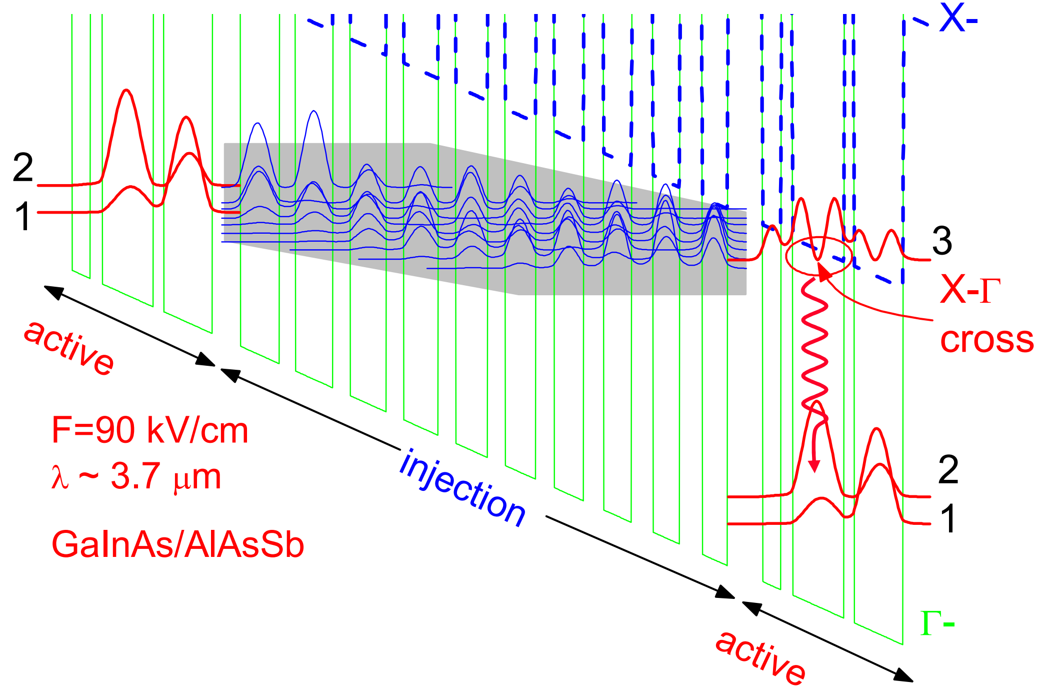
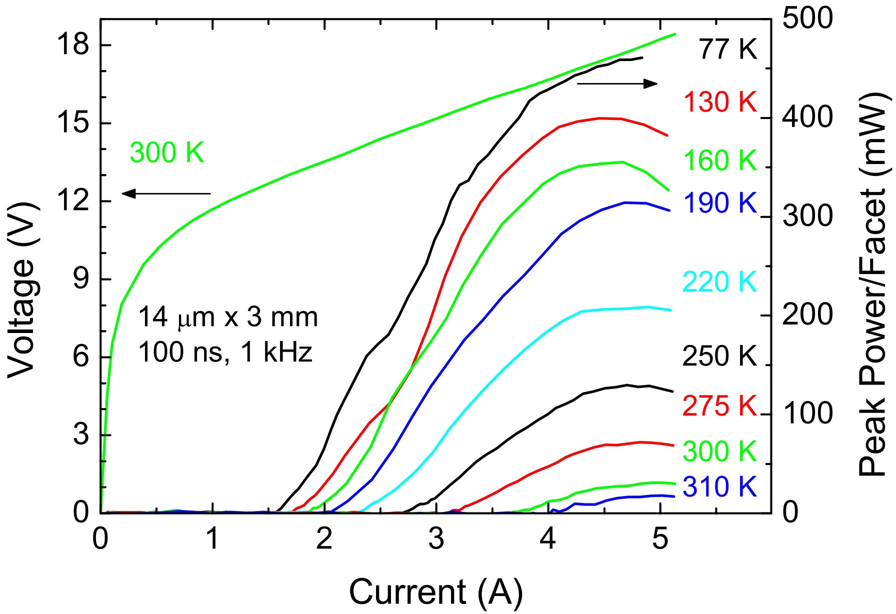
Towards shorter wavelengths: Γ-X scattering



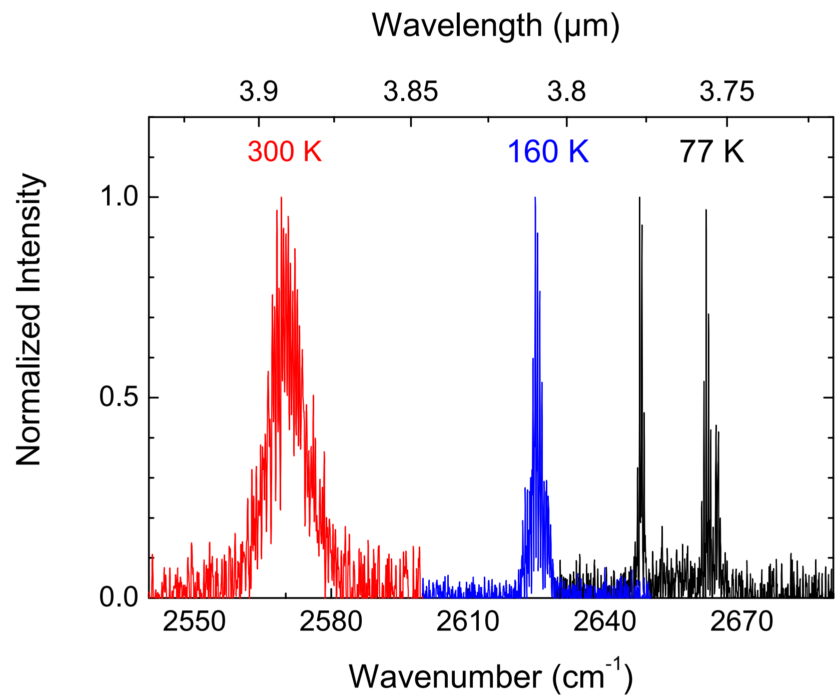


Q. Yang et al., Appl. Phys. Lett. 88, 121127 (2006)

Short-wavelength (λ ~ 3.7-3.9 µm) GaInAs/AlAsSb QC lasers



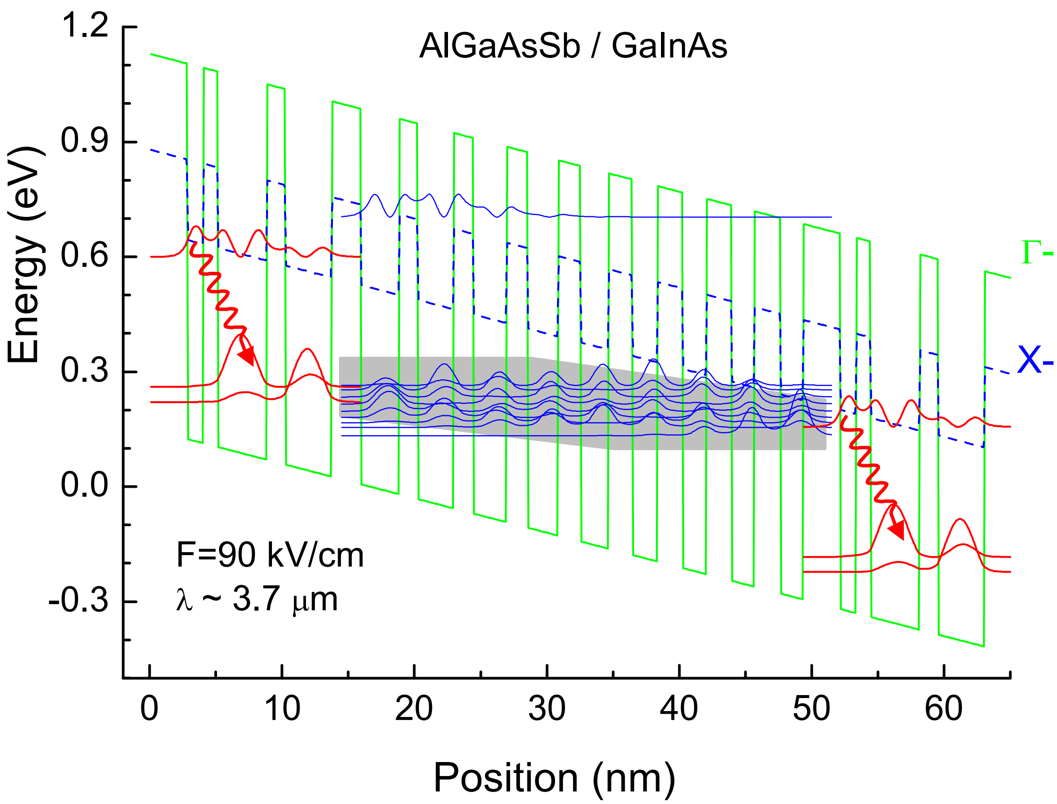
P-I-characteristics



Lasing spectra

Q. Yang et al., Appl. Phys. Lett. 88, 121127 (2006)

High peak power QC Lasers



- **Quaternary barrier (AlGaAsSb) instead of ternary barrier (AlAsSb): lattice-matched**

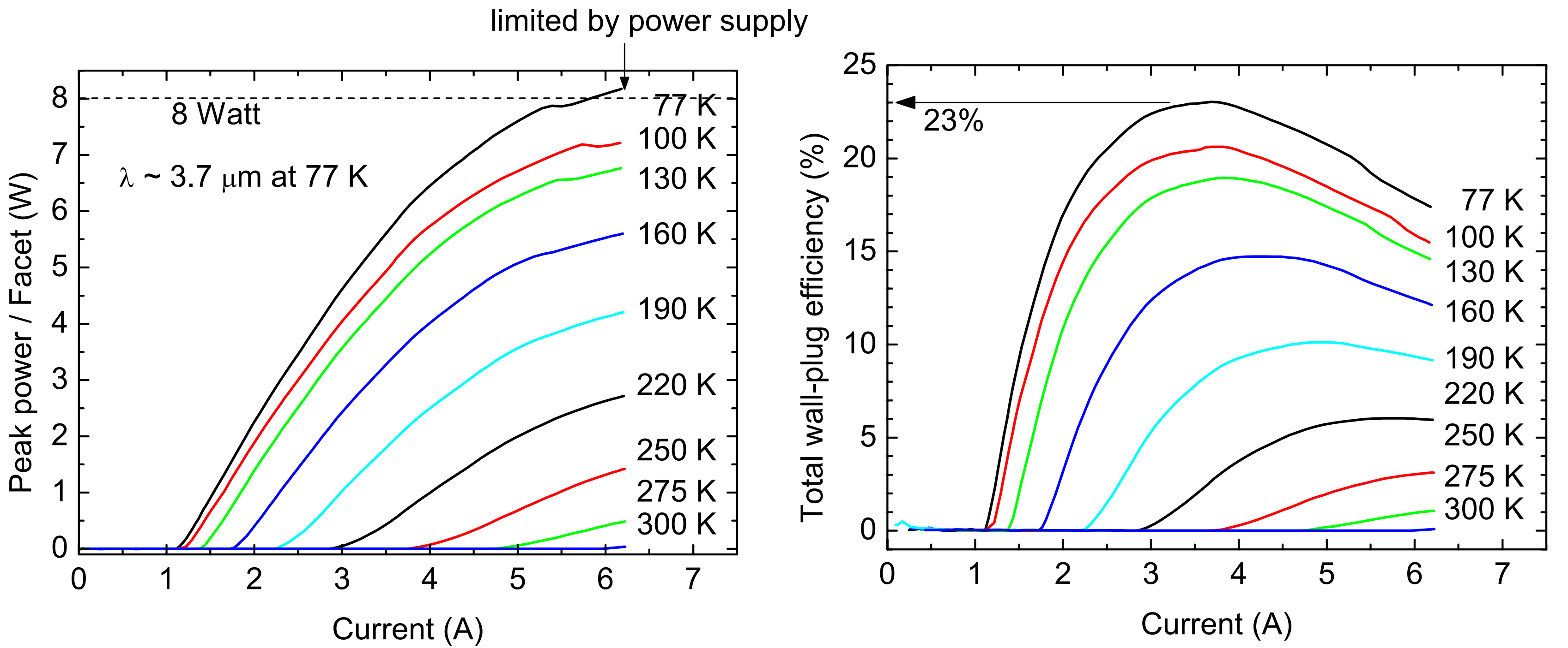
  $Ga_{0.47}In_{0.53}As$ / $Al_{0.67}Ga_{0.33}As_{0.55}Sb_{0.45}$

  $\Rightarrow \Delta E_c(\Gamma) \approx 1$ eV

  $\Rightarrow$ better tunneling probability

- **Slightly diagonal transition**

High peak power λ~3.7 µm GaInAs/AlGaAsSb QC lasers



At 77 K: P_{max} > 8 W/facet (pulsed, uncoated facets),

Total wall-plug efficiency η_{max} = 23%, η_D (total) = 1605%, η_D (per stage) = 54%

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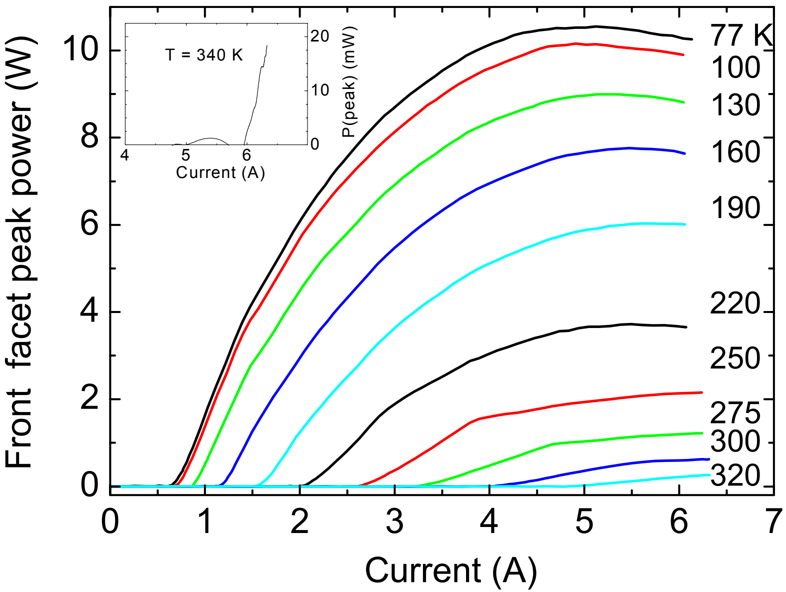
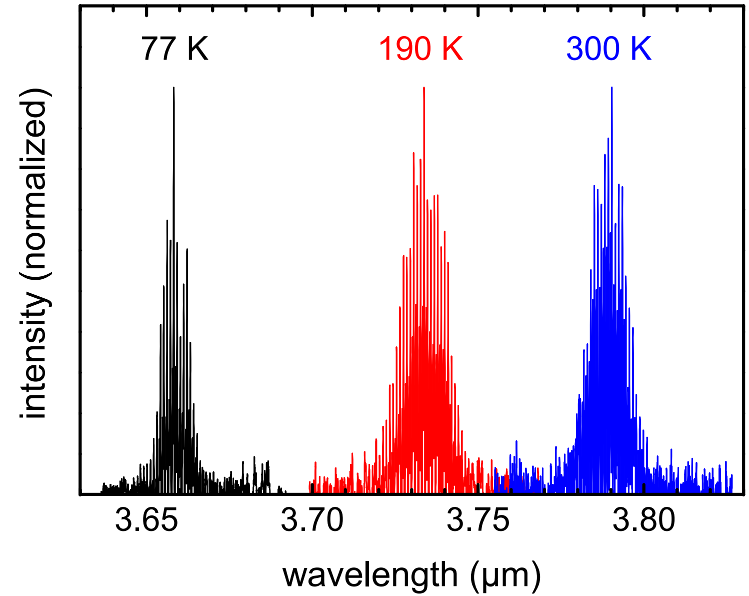
High (peak) power capability of GaInAs/AlGaAsSb QCL @3.7 μm





device: 18 x 2000 μm²
HR/uncoated
100 ns / 1-5 kHz

- λ @ 77 K: 3.65 μm; λ @ 300 K: 3.79 μm
- P_{max} 10.5 W @ 77 K; 2.1 W @ 250 K
- max. pulsed operation temperature: 340 K

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Summary:

- Summary
  - GaInAs/AlAsSb QC lasers **(λ ~ 4.5 µm)** operating **up to 400 K**
  - **3-QW vertical-transition (λ ~ 3.7-3.9 µm)** GaInAs/AlAsSb QC lasers
  - High peak power **(10 W, pulsed operation at 77 K)** GaInAs/AlGaAsSb QC lasers demonstrated at **λ ~ 3.7 µm**

- Financial support: EU project “ANSWER”

Future R&D challenges of GaInAs/AlAsSb QC lasers

- Gain spectrum is still significantly broader than for comparable GaInAs/AlInAs QC lasers (→ severely limits high-temp. & cw performance)
  → to be solved by improved MBE growth?
  → inherent to QC active region with group-V constituents changing at well/barrier interface?

- Which are the short-wavelength limitations of GaInAs/AlAsSb QC lasers? (Γ-X scattering in the well and/or barrier?)