InP-based QC lasers: towards shorter wavelengths and new applications

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Outline:

- Short-wavelength GaInAs/Al(Ga)AsSb QC lasers: current state-of-the-art and future challenges

- Towards applications other than high-resolution trace gas spectroscopy: requirements for QC laser and need for MIR optical components
GaInAs/AlInAs DFB-QC lasers for trace gas detection

- **Wavelength (µm)**
  - 700
  - 750
  - 800
  - 850
- **DFB grating period (nm)**
  - 4.4
  - 4.6
  - 4.8
  - 5.0
  - 5.2
  - 5.4
  - 5.6
- **T = 300 K**
- **100 ns, 5 kHz**
- **Line strength (cm / molecule)**
  - N2O
  - CO
- **Wavenumber (cm^{-1})**
  - 1827.9
  - 1828.0
  - 1828.1
  - 1828.2
- **Absorbance**
  - 70 ppmv NO
  - Measurement
  - HITRAN96
  - 70 ppmv NO
  - 56
  - 42
  - 28
  - 14
GaInAs/AlInAs QC laser on InP substrate

max. operating temperature (K)

emission wavelength (µm)

1/2006

pulsed

cw

literature

IAF QC laser

RT

Peltier cooling

LN₂ cooling

LHe cooling
Short-wavelength limitations of QC lasers

- thermionic emission into continuum
  \[ \Gamma_{\text{therm}} \propto \exp\left[-\frac{H_{\text{eff}}}{(k_B T)}\right] \]

- tunneling
  \[ \Gamma_{\text{tunnel}} \propto \exp\left[-2L\sqrt{2m^*H_{\text{eff}}/\hbar}\right] \]

→ large \( \Delta E_c \) required for “short wavelength” QC lasers
rule-of-thumb:
\[ \Delta E_{32} \leq \frac{\Delta E_c}{2}, \text{ or } \lambda (\mu m) \geq \frac{2.48}{\Delta E_c} (eV) \]
**InP-based materials combinations with large $\Delta E_C$**

- **InP substrate**
  - $\text{Ga}_{0.47}\text{In}_{0.53}\text{As} / \text{Al}_{0.48}\text{In}_{0.52}\text{As}$
  - (lattice-matched)
  - Energy difference: 510 meV

- **InP substrate**
  - $\text{Ga}_{0.38}\text{In}_{0.62}\text{As} / \text{Al}_{0.6}\text{In}_{0.4}\text{As}$
  - (strain-compensated)
  - Energy difference: 720 meV

- **InP substrate**
  - $\text{Ga}_{0.47}\text{In}_{0.53}\text{As} / \text{AlAs}_{0.56}\text{Sb}_{0.44}$
  - (lattice-matched)
  - Energy difference: 1600 meV
GaInAs/AlAsSb QC laser performance @ 4.5 μm

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

Towards shorter wavelengths: $\Gamma$-X scattering

$\Gamma$-valley

$X$-valley

$\lambda \approx 3.7 \, \mu m$

GaInAs/AlAsSb

F=90 kV/cm

$\lambda \approx 3.7 \, \mu m$

GaInAs/AlAsSb

Short-wavelength ($\lambda \sim 3.7$-$3.9$ μm) GaInAs/AlAsSb QC lasers

P-I-characteristics

Lasing spectra

Short-wavelength ($\lambda \sim 3.7$-$3.9$ μm) GaInAs/AlAsSb QC lasers

P-I-characteristics

T-dependence of $I_{th}$

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

- maximum operating temperature: 333 K (60 °C)
- maximum peak power: 10.1 W @ 77 K, 2.1 W @ 250 K
- maximum power efficiency: 21 % @ 77 K, 3 % @ 250 K

device: 18 x 2000 µm²
HR-coated
100 ns / 1-5 kHz
Future R&D challenges of GaInAs/AlAsSb QC laser

• 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?)
Towards new applications: detection of complex molecules, e.g. explosives

- characteristic absorption lines in the MIR spectral range
- more complex absorption spectra $\rightarrow$ broadened absorption lines
- QC laser requirements
  - larger tuning range
  - not necessarily single-mode operation
- challenges
development of suitable tunable QC laser modules and detection schemes
Options for extended tuning range QC laser modules

- Rapid temperature tuning (*top right*) of (Fabry-Perot) QC laser via large $\Delta T$ submounts ($\Delta T>100$ K) (*bottom right*)

  Issue: lasing spectra of FP-QC lasers at higher output powers

- Large tuning range external cavity QC laser (see e.g. recent work by Neuchatel group and Daylight Solutions)
Towards high-power / high-brightness QC laser systems

- Certain application require average output powers exceeding that of a single QC laser

- Thus beam combining of several QC lasers with simultaneously good beam quality is required

- Challenges:
  - large beam divergence of typical QC laser (typ. 30° x 100° FW(1/e²) @ 4.7 μm)
  - availability and cost of MIR optical components (lenses, fibers, beam splitters etc.)
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