THz photonic crystal resonators

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Photonic crystal (PhC) resonators

- THz QCLs with double-metal waveguide
- PhC with full gap for TM-modes used as reflectors
- Further reduction of facet losses
- High-Q cavities
- Modes shifted to bandgap of PhC
- Outside bandgap increased losses

Photonic crystals ↔ THz QCLs

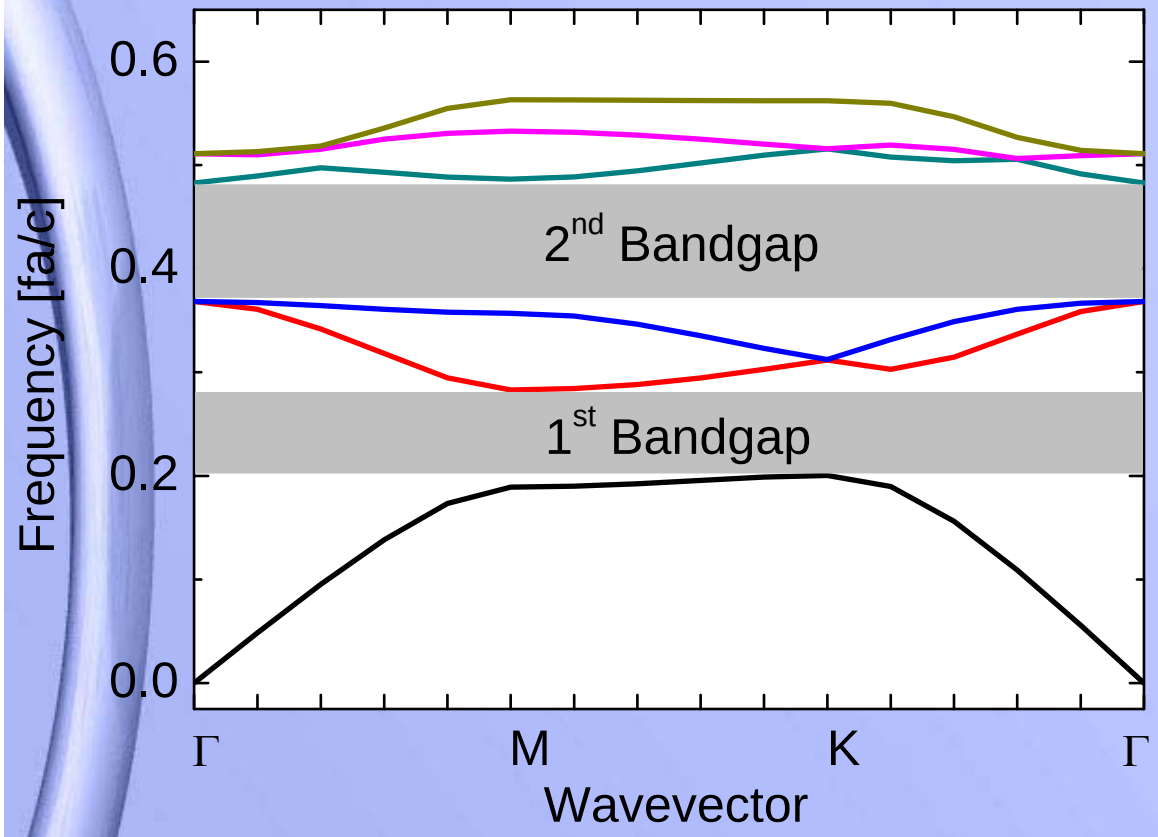
- THz quantum-cascade lasers (QCLs) have reached a high grade of maturity [1]
  - Low frequencies 0.83 THz [2]
  - Lasing up to 164 K [3]
  - Peak output powers of 248 mW [4]
- Compact sources of THz radiation
- Light guiding solutions
- Photonic circuits

[1] R. Köhler et al., Nature 417, 156 (2002)
[2] G. Scalari er al, ITQW 2007
[3] B. S. Williams et al., Opt. Exp. 13, 3331 (2004)
[4] B. S. Williams et al., Elec. Lett. 42, 89 (2006)

THz photonic crystals (PhC)

- Integration into bandgap laser suffers from increased surface recombination
- QCL doesn‘t show that effect, ideal for minituarization
- TM-polarization of QCL-modes
  - Emits in-plane
  - Planar processing technology
  - Results in 2D-PhC
- Large wavelength (60 to 350 μm) of THz-QCLs makes the fabrication easy
  - Period of the PhC in the order of the wavelength

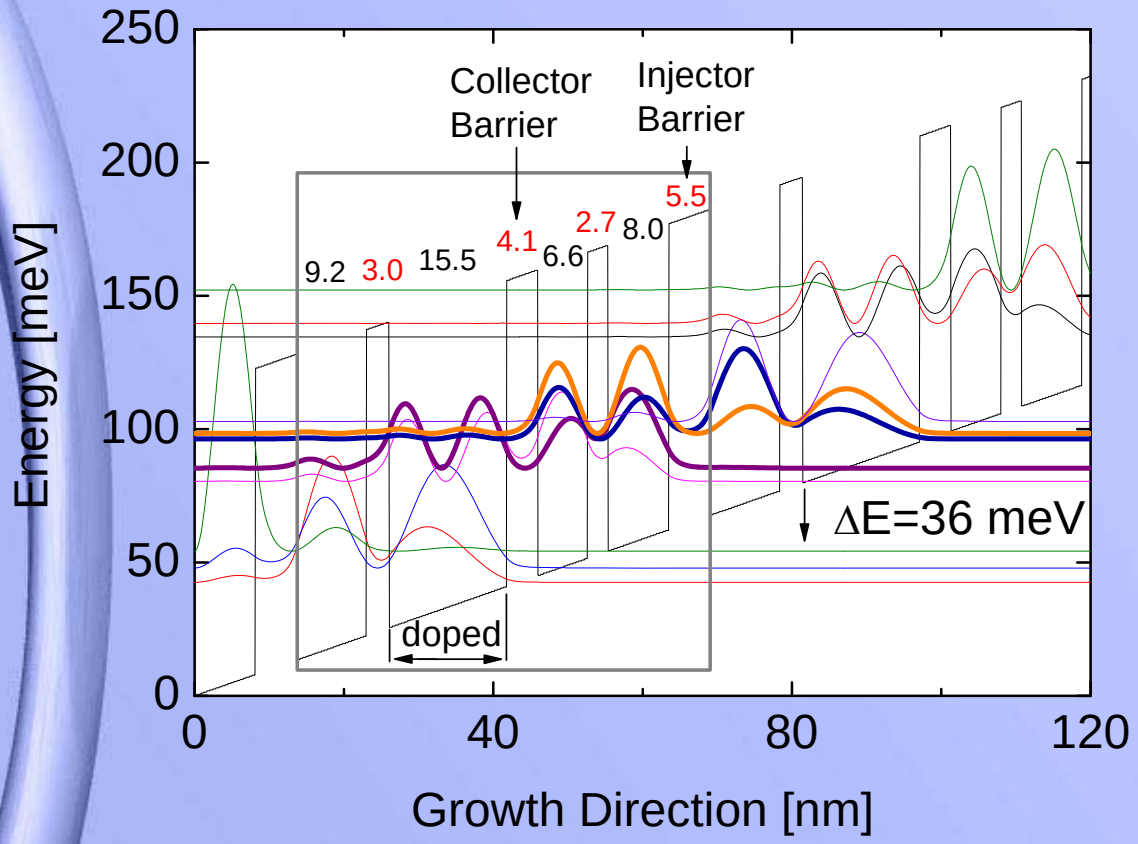
PhC band structure



- 2D-model used [1]
- Dielectric rods surrounded by air
- Rods are infinetely high
- n_{eff}=3.9
- Bandgaps for TM:
  - 1st: .2 to .28
  - 2nd: .37 to .48

[1] S.G. Johnson et al., Opt. Exp. 8 173 (2001)

QCL band structure

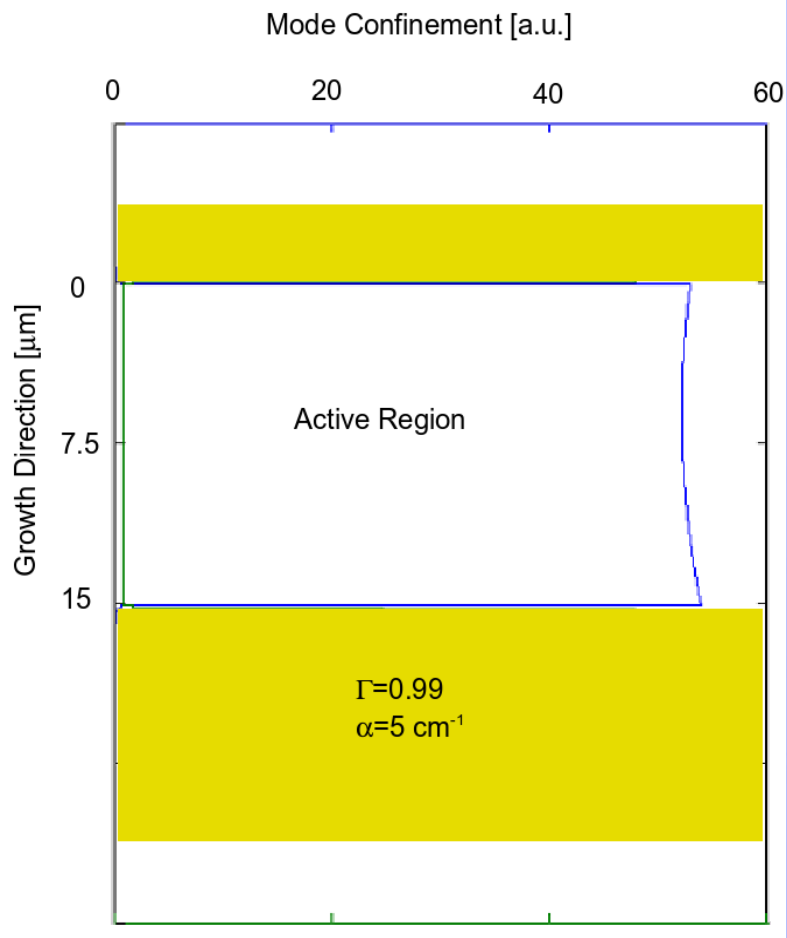


- LO-phonon depopulation design [1]
- Transition energy 12 meV
- 15 μm active region
- Two different samples used [2]:
  - (a) 2.8 THz
  - (b) 2.5 THz

[1] S. Kumar et al., Appl. Phys. Lett. 84, 2494 (2004)

[2] A. Benz et al., Appl. Phys. Lett. 90, 101107 (2007)

Double-metal wave guide



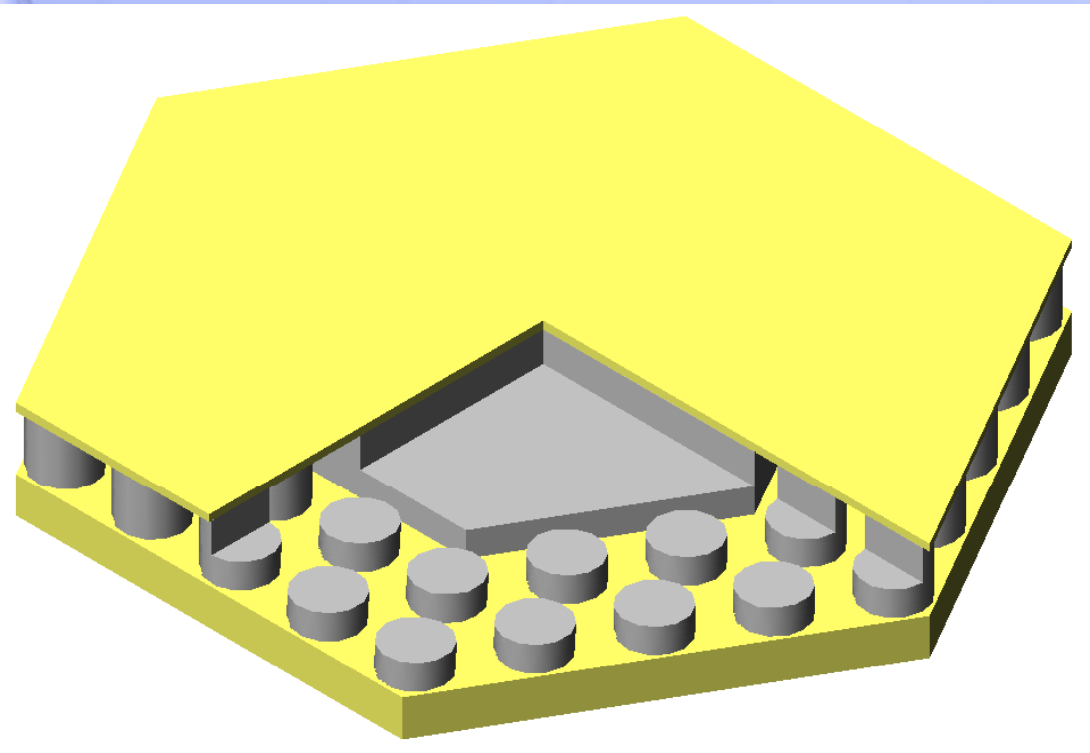
- Confinement near unity
- Low losses, α=5 cm^{-1}
- Only 1st order mode in vertical direction can propagate
- No out-of plane scattering
- Proven to be excellent wave guide for THz-QCLs [1, 2, 3]
  - Resonators with sub-wave length dimensions

[1] G. Fasching et al., IEEE J. Quantum Elec. 43, 687(2007)

[2] Y. Chassagneux et al., Appl. Phys. Lett. 90, 091113 (2007)

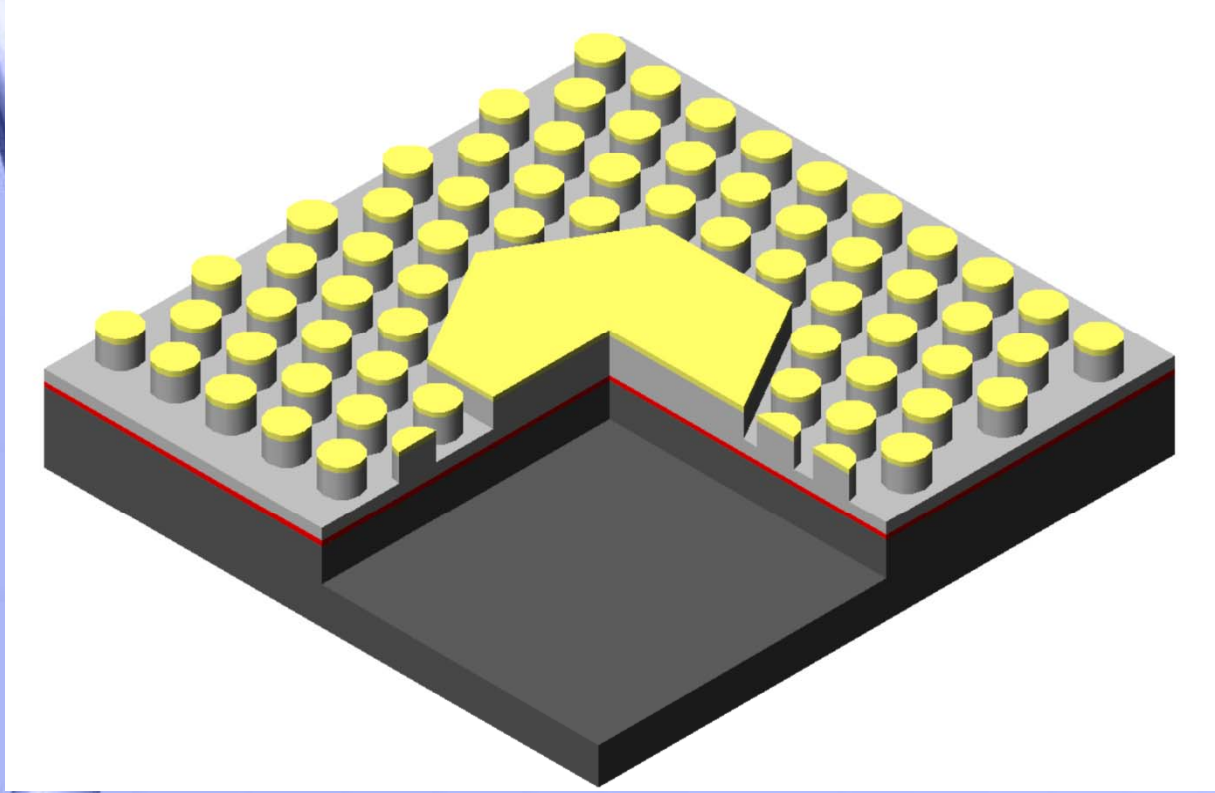
[3] L. A. Dunbar et al., Appl. Phys. Lett. 90, 141114 (2007)

PhC resonator



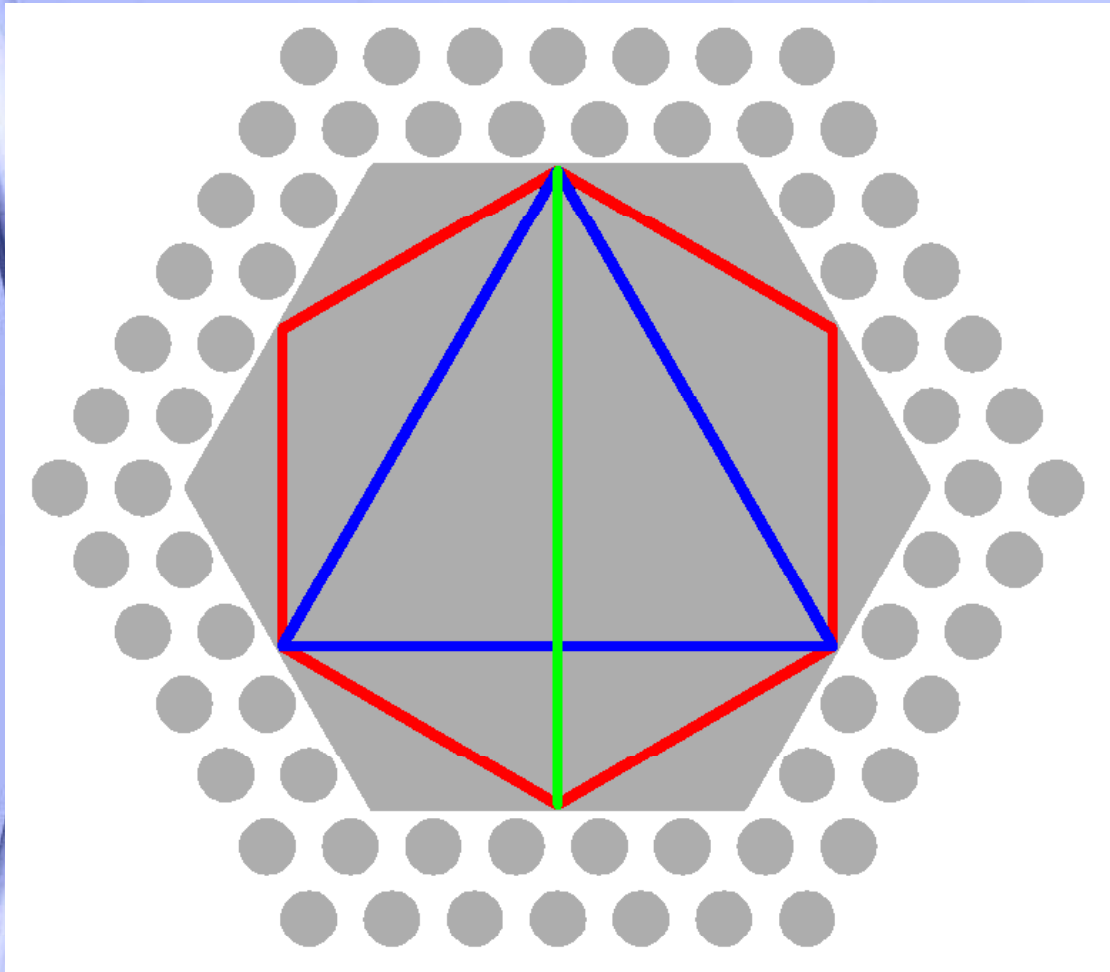
- Emission from facet
- Strong vertical confinment
- No mode leakage, problem for dielectric wave guides
- Lateral confinement by PhC
- Pillars are pumped but not supporting own modes

PhC processing



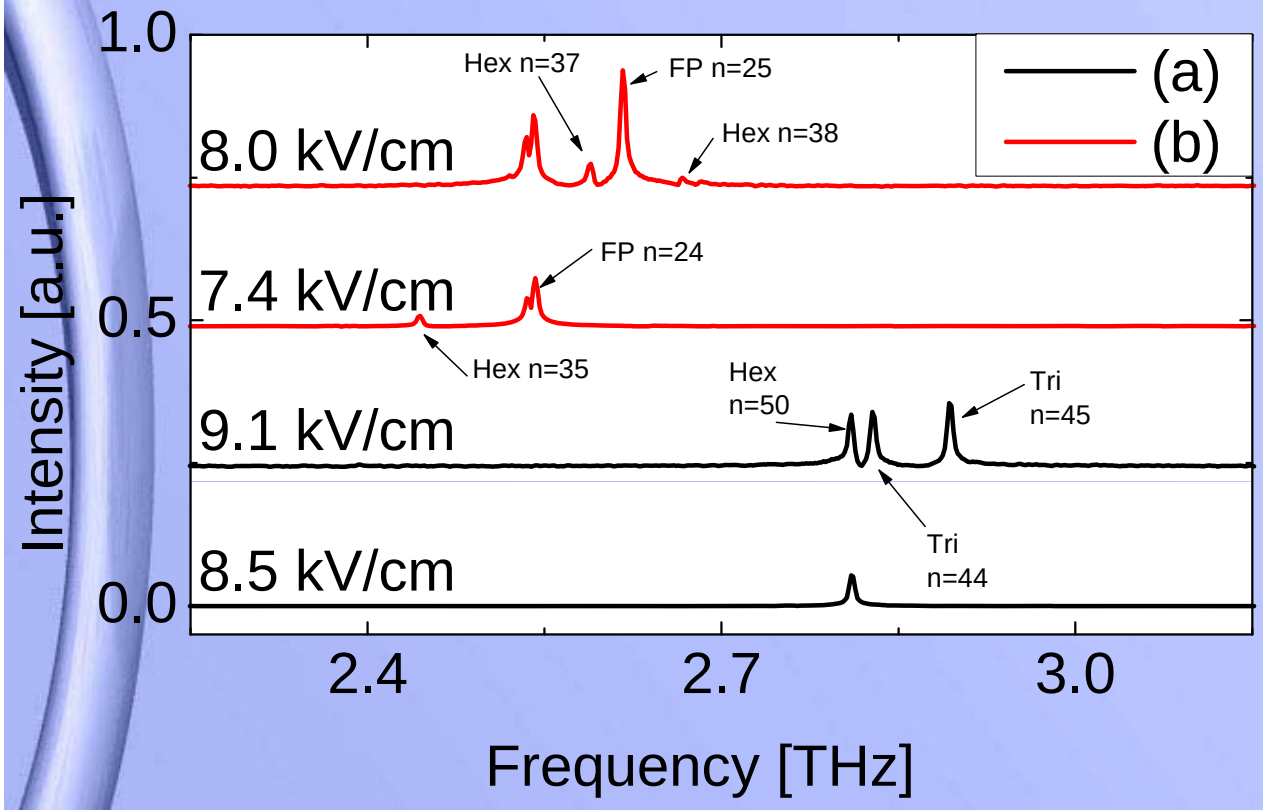
- Metal deposition, structure by opt. lithographie
- RIE etching
- Wafer bonding
- 2nd metal deposition step
- 2nd RIE etching step

Resonator modes



- Three dominant modes:
  - Fabry-Perot
  - Triangular
  - Hexagonal
- Different optical path leads to different mode spacing

Reference spectra



- Sample (a) emits between 2.8 and 2.9 THz
- Sample (b) between 2.45 and 2.7 THz
- Samples emit in the gain maximum of the active region

[1] A. Benz et al., Opt. Exp. (to be published)

Summary

- PhC used as a frequency selective mirror
- Double-metal waveguide used
- Mode is forced to propagate through the PhC
- Emission shifted from the maximum gain to band gap of the PhC
- Mirror provides the lowest losses
- Modes identified as resonator modes of the hexagonally shaped core
- No singel mode in general due to broad band gap


Thank you for your
attetion!