Photonic Crystals Quantum Cascade Lasers in THz regime

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Outline

- Motivation
- Introduction
  - Quantum cascade laser (QCL)
  - Surface plasmon guide
- Photonic crystals QCL
  - Surface emission and distributed feedback
  - Electrically pumped photonic crystal THz QCL
- Conclusions
Terahertz radiation

- Loosely defined as EM spectrum between 0.5 THz and 5 THz
- Applications in different areas of science and technology, such as astronomy, environmental monitoring and security
Quantum Cascade Laser

Proposed: Kazarinov and Suris (1971) Realization: J. Faist et al. (Bell Labs, 1994)

Active region: stack of quantum wells of two different materials (GaAs and AlGaAs for example)

Electrical pumping; conditions for resonant tunneling achieved by applied voltage

Intersubband transition $\rightarrow$ unipolar device and wavelength $\lambda$ given by structure design

Hofstetter D. et al. APL 75, 24 (1999)
Properties of QCL

- Electrically pumped semiconductor source for coherent emission in the long wavelength regime → good system to study photonic crystals
- Wavelength can be tuned by design and does not depend on bandgap of material
- Unipolar device less leakage currents due to surface recombination (in contrast to diodes)
- Intrinsically in plane emitter due to TM polarization of intraband transition → cleaved edges can be used as mirrors → low feedback → normally multimode emission
- Single mode and surface emission are desired
Surface plasmon resonance (SPR) waveguide


- Surface plasmon
  - EM wave which propagates at the surface of a metal
  - Arise from the coupling of the photonic field to the free carriers of the metal (also known as surface plasmon polaritons)
- Key ingredient for QCL in THz regime
One dimensional photonic crystal

Hofstetter D. et al. APL 75, 24 (1999)

- Grating changes periodically refractive index for surface plasmon and provides distributed feedback ($\lambda/4$ condition for Bragg reflection) and diffraction for surface emission
- Efficiency of surface emission and beam properties are not optimal

- Flat region in dispersion curve ➔ high density of states and no in plane propagation (standing waves) ➔ distributed feedback
- Energy of flat regions can be tuned by PC design ➔ overlap with QCL gain
- Single mode and surface emission through distributed feedback and Bragg diffraction
- Energy of emission peaks changes as a function of $a$ and $r$ and lasing always starts at the lowest energy of region A $\rightarrow$ band edge lasing and not defect mode lasing.
Surface emitting THz QCL

- Mesa etched down to bottom in order to avoid lateral current dispersion
- Photonic crystal only on top layer
- Different boundary conditions were realized
  - Mirror conditions when conducting layer removed at edge
  - Absorbing conditions when layer left in place
- PC pattern with connected nature important for electrical injection

Curves of devices with mirror boundary conditions do not strongly depend on photonic crystal design → lasing on whispering gallery modes (multimode)

Photonic crystal lasing only for absorbing boundary conditions
Far field emission of THz laser

b: control device without PC
c and d: devices with mirror boundary conditions
e and f: devices with absorbing boundary conditions

- Directional lasing only for photonic crystal band edge lasing
Conclusion

- Electrically pumped Terahertz Quantum Cascade Laser with single mode and surface emission due to photonic crystal design has been shown.
- Boundary conditions play a crucial role for the operation of the laser.
- This opens the way for new THz technological applications.