Intersubband Absorption Loss for 10.3µm Quantum Cascade Lasers

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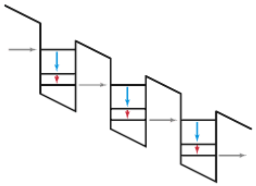
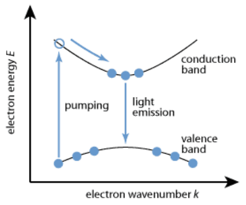
Background

- QCL's are semiconductor devices that emit light in the mid to far infrared
- They emit multiple photons per electron, as opposed to traditional lasers which emit only one photon per electron, for each trip through the device
- Electrons make intersubband transitions, as opposed to interband transitions

Intersubband vs. Interband Transitions

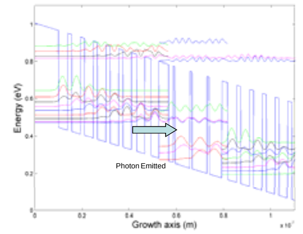


Intersubband transition in a QCL



Interband transition in a traditional semiconductor laser

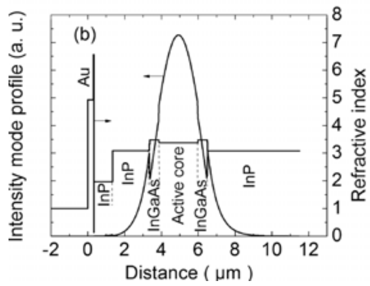
10.3µm QCL Design



Princeton University structure

QCL Diagram

Z. Liu, *et al.*, IEEE Photon. Technol. Lett., **18**, 1347 (2006)



Sources of Loss

Intersubband Absorption

For one transition:

$$\alpha_{\mathrm{ISB}}(\omega)=\frac{4\pi e}{\varepsilon_0 n}\frac{\pi}{2L_p}n_{\mathrm{2D}}\frac{\langle z_{qi}\rangle^2}{\lambda_{qi}}\frac{\gamma_{qi}/\pi}{(E_{qi}-\hbar\omega)^2+\gamma_{qi}^2}$$

For the entire device:

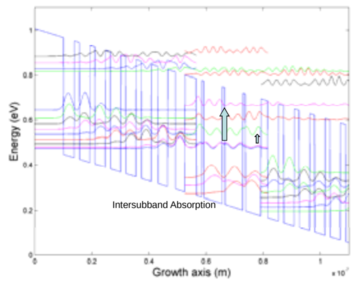
$$\alpha_{\mathrm{ISB}}(\omega)=\frac{4\pi e}{\varepsilon_0 n}\frac{\pi}{2L_p}n_{\mathrm{2D}}\sum_q\frac{\langle z_{qi}\rangle^2}{\lambda_{qi}}\frac{\gamma_{qi}/\pi}{(E_{qi}-\hbar\omega)^2+\gamma_{qi}^2}$$

Free carrier absorption in the waveguide

$$\alpha_{fc}\sim\frac{N_e e^2\gamma}{\eta_0 m_c\omega^2}$$

As energy increases, free carrier absorption gets less significant relative to the off-resonant intersubband absorption

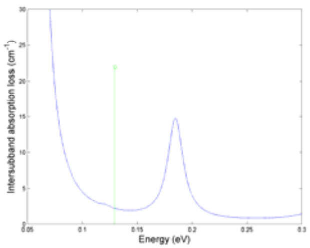
Loss in Diagram



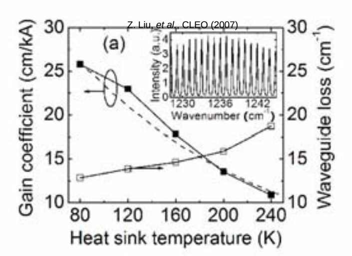
The Shooting Method

- Computational method used to solve wave equations
- Reduces boundary value problems into initial value problems
- Used to "shoot" electrons and look for resonance in wave equations

Results



calculated results



experimental results

Conclusions

- Loss in the active region is an important performance parameter
- It is crucial to design the laser active region to avoid gain/loss overlap.
- Experimental results and calculated results are similar, but not completely
- Future work: optimizing the model