LO-phonon emission by hot electrons in terahertz quantum cascade lasers

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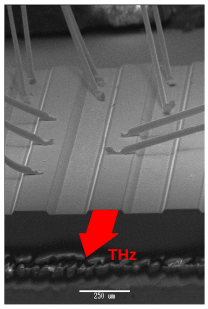
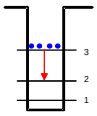
Principle of Quantum Cascade laser

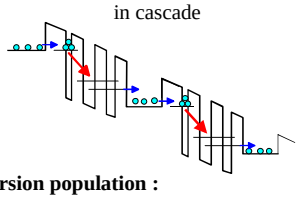


Intersubband emission



Unipolar device

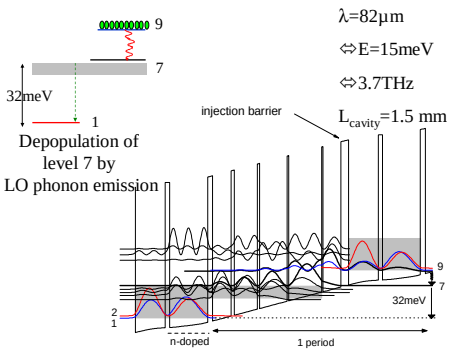
Active region and injection in cascade



Need to establish an inversion population :
- Good injection in the upper laser state
- Fast depopulation of lower laser state

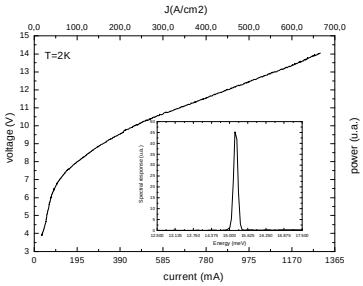
Different ways to succeed this inversion population :
- Chirped superlattice
- Bound to continuum design
- Resonant LO-phonon depopulation design

New type of structure

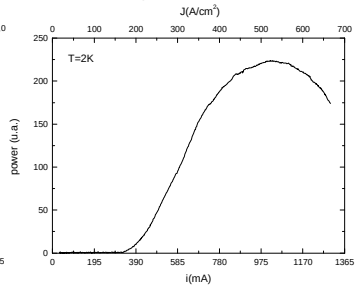


Laser characteristics at B = 0T

I-V characteristics and emission spectrum



Light versus current



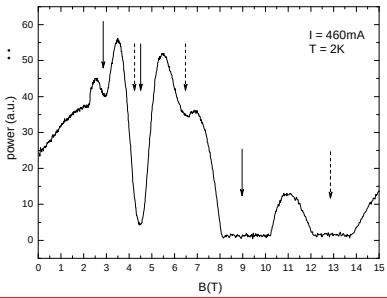
Use of magnetic field - experimental results

THz QCLs are complex structures :
- Many channels of relaxation

Study of these non-radiative mechanisms :
- Magnetic field,

Under B each subband splits into discrete Landau levels

Laser emission as a function of magnetic field



Interpretation

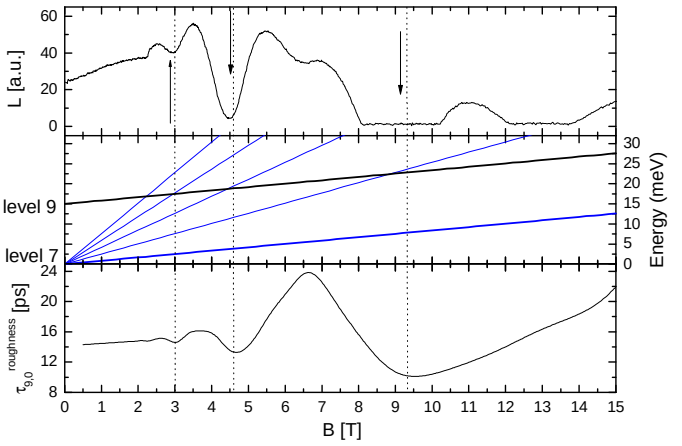
Interaction electron-interface roughness (Elastic)

Calculated upper state lifetime considering the relaxation via the interface roughness scattering from $|9,0\rangle$ Landau level to the Landau levels of all the subbands of the extraction miniband .

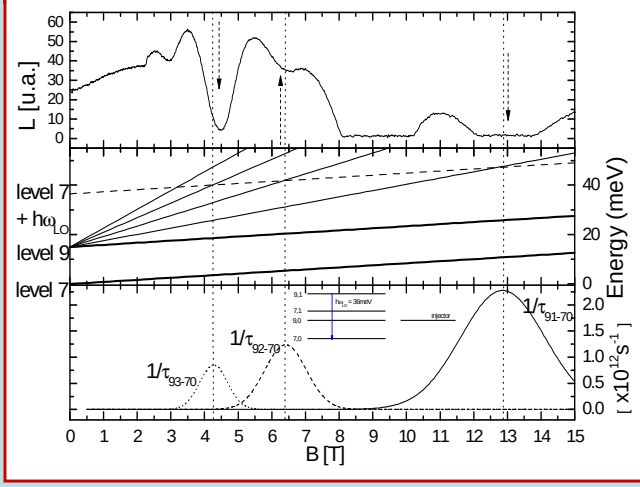
$$E_{90}+\frac{1}{2}\hbar\omega_c = E_{70}+\left(m+\frac{1}{2}\right)\hbar\omega_c$$

$$with\ m = 1,2,3,...$$

$$\frac{1}{\tau^{roughness}_{9,0}} = \sum_n \left(\frac{1}{\tau^{roughness}_{9,0-7,n}} + \sum_{i=3}^{6} \frac{1}{\tau^{roughness}_{9,0-i,n}} \right)$$



Interaction electron-LO phonon (Inelastic)



$$E_{90}+\left(n+\frac{1}{2}\right)\hbar\omega_c = E_{70}+\frac{1}{2}\hbar\omega_c+\hbar\omega_{LO}$$

$$with\ n = 1,2,3,...$$

This series of oscillations implies a hot electrons population injected in Landau levels $|9,n\rangle$. (T_e = 150K)

Using a complete set of rate equations for levels $|9\rangle$ and $|7\rangle$, we demonstrate this non radiative mechanism breaks inversion population.

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Conclusion

- Two non-radiative mechanisms are pointed out in this sample
- Demonstration of high electronic temperature
- Need to lower electronic temperature in QCL by new design