NONEQUILIBRIUM ELECTRON-ELECTRON SCATTERING IN POSSIBLE FAR-INFRARED QUANTUM CASCADE LASER

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In the mid-infrared quantum cascade laser, the seminal recent achievement by Dr. Capasso and co-workers, a strong current injection exclusively into the upper resonant level E_2 of a multiple-quantum-well tunneling structure provides a finite *intersubband* population inversion *if* the tunneling escape rate, Γ_{c1} out from the lower level E_1 *exceeds* the total intersubband decay rate Γ_{nr}. A finite population inversion density $\sim 10^{11}$ cm^{-2} provides a significant net stimulated emission because the intersubband optical transitions is strongly enhanced at a frequency ω_Δ given by the subband separation $\Delta \equiv E_2 - E_1$ and is characterized by large dipole matrix elements.

We consider a hypothetical quantum-cascade-laser design with a far-infrared subband separation $\Delta \sim 10$ meV. We find that an existing measurement of the decay rate bounds the total *single*-electron decay at $\Gamma_{se} \leq 0.03$ meV at temperatures $T \leq 25$ K — a decay rate much smaller than the estimated lower-level tunneling escape rate $\Gamma_{c1} \sim 0.5$ meV.

We find, however, that the measured large depolarization shift, $\Delta^* - \Delta \sim 2$ meV, of the equilibrium absorption peak, Δ^*, indicates a very significant nonequilibrium electron-electron scattering (Γ) which we evaluate for a complete upper-subband occupation below the emitter lead chemical potential. This scattering Γ involves two upper-subband electrons which both decays to subband E_1, and is never significantly reduced by screening nor affected by the Pauli exclusion.

In this dissertation we consequently: (1) identify a simple scaling of Γ with the upper-subband electron occupation, (2) predict a very strong intersubband decay $\sim 2\Gamma \approx 1$ meV for an upper-subband occupation density, $n_2 \approx 10^{11}$ cm^{-2}, (3) demonstrate that a smaller population inversion density ($\sim 0.2 \times 10^{11}$ cm^{-2}) *can* be maintained at a moderate current density, and finally (4) predict for the nonequilibrium electron-electron scattering a dramatic voltage-drop dependence arising from the so-called quantum-confined Stark effect on the wavefunction symmetry.