Coherent Population Trapping in an Island Quantum Well

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Coherent Population Trapping in an Island Well

• Introduction
  - Electromagnetically Induced Transparency (EIT) and Coherent Population Trapping (CPT)
  - Three Level Systems
  - Multiple Quantum Well (MQW) Structures
  - Current Quantum Interference Studies in QW Systems

• Structures
  - Single Well, Staggered Well, Double Well and Triple Well Designs
  - Island Well

• Design and Simulation
  - Lattice matching to InP
  - Designing the shallow well
  - Numerical results

• Conclusion
Electromagnetically Induced Transparency

Cascade System  \hspace{1cm} \Lambda \text{ System} \hspace{1cm} V \text{ System}

Coherent Population Trapping

\[ \chi^{(1)}_{\Lambda,\Xi} = -i \frac{2N|\mu_{ba}|^2}{\varepsilon_0 \hbar} \frac{(i\delta - \Gamma_{ca})}{(i\Delta_1 - \Gamma_{ba})(i\delta - \Gamma_{ca}) + |\Omega_2 / 2|^2} \]

\[ \chi^{(1)}_V = -i \frac{N|\mu_{ba}|^2}{\varepsilon_0 \hbar} \frac{\left[(i\delta - \Gamma_{ca})(-i\Delta_2 - \Gamma_{bc}) + |\Omega_2 / 2|^2\right]}{(i\Delta_1 - \Gamma_{ba})\left[(i\delta - \Gamma_{ca})(-i\Delta_2 - \Gamma_{bc}) + |\Omega_2 / 2|^2\right] - |\Omega_2 / 2|^2 (i\Delta_2 + \Gamma_{bc})} \]
Electromagnetically Induced Transparency

Cascade System  Λ System  V System

Coherent Population Trapping

Ω_{cb} = 1/T_1, \gamma_{ca} = 10^{-3}/T_1
Multiple Quantum Well Structure

\[ E_n = \frac{\hbar^2 \pi^2}{2m^*} \left( \frac{n^2}{W^2} \right) \]
Multiple Quantum Well Structure
Fano interference
- Transparency window (Fano profile) due to coupling to the continuum.

Tunnelling induced transparency
- Tunnelling induced transparency: Similar to EIT but with the driving field replaced with the process of tunnelling.

EIT in a cascade system
- Cascade system in a single quantum well.
Various Structures for Observing CPT

Single Well
Various Structures for Observing CPT

Staggered Well
Various Structures for Observing CPT

Double Well
Various Structures for Observing CPT

Triple Well
Three-Level $\Lambda$ System in an Island Well

(i) AlAs$_{56}$Sb$_{44}$ barrier
(ii) In$_{53}$Ga$_{47}$As deep well
(iii) (GaAs$_{51}$Sb$_{49}$)$_4$(AlAs$_{56}$Sb$_{44}$)$_6$ shallow well

Lattice-matched to InP.
Quaternary alloy for the shallow well: \((\text{GaAs}_{0.51}\text{Sb}_{0.49})_{1-x}(\text{AlAs}_{0.56}\text{Sb}_{0.44})_x\)
Design of the Shallow Well

Eigenvalues of the island well

Coupling rates between various levels

Well 1 width = 2.6 nm, island width = 10 nm, well 2 width = 1.9 nm
Simulation Results

\[ \Omega_{ca} = 0.036 \text{ ps}^{-1} \]
\[ \Omega_{ca} = 0.08 \text{ ps}^{-1} \]
\[ \Omega_{ca} = 0.113 \text{ ps}^{-1} \]
\[ \Omega_{ca} = 0.252 \text{ ps}^{-1} \]
\[ \Omega_{ca} = 0.356 \text{ ps}^{-1} \]

\[ \langle \Psi_c | z | \Psi_a \rangle = 0.27 \text{ e [nm]} \]
\[ \langle \Psi_c | z | \Psi_b \rangle = 0.11 \text{ e [nm]} \]
\[ \gamma_{p,ac} = \gamma_{p,ac} = 0.1 \text{ [ps}^{-1}] \]
\[ \gamma_{p,ac} = 2 \times 10^{-5} \text{ [ps}^{-1}] \]
\[ \gamma_{e,aa} = \gamma_{e,bb} = 10^{-2} \text{ [ps}^{-1}] \]
Conclusion

• Need to utilize coherent population trapping (CPT) to achieve a better and narrower transmission window.

• Island well design is optimal for creating a Λ system necessary for CPT.

• Simulation results show that it is possible to observe CPT with our ternary-quaternary system.