Coherent Population Trapping in an Island Quantum Well

Vincent Wong, Aaron Schweinsberg, and Robert W. Boyd

The Institute of Optics, University of Rochester, NY14627, USA

Acknowledgements to

the Office of Naval Research and the Department of Energy

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

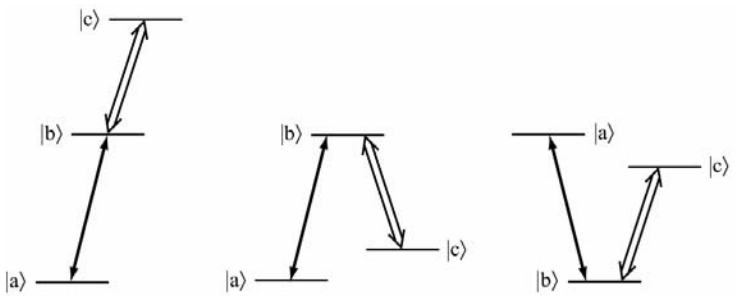
Electromagnetically Induced Transparency

Cascade System Λ System V System

Coherent Population Trapping

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

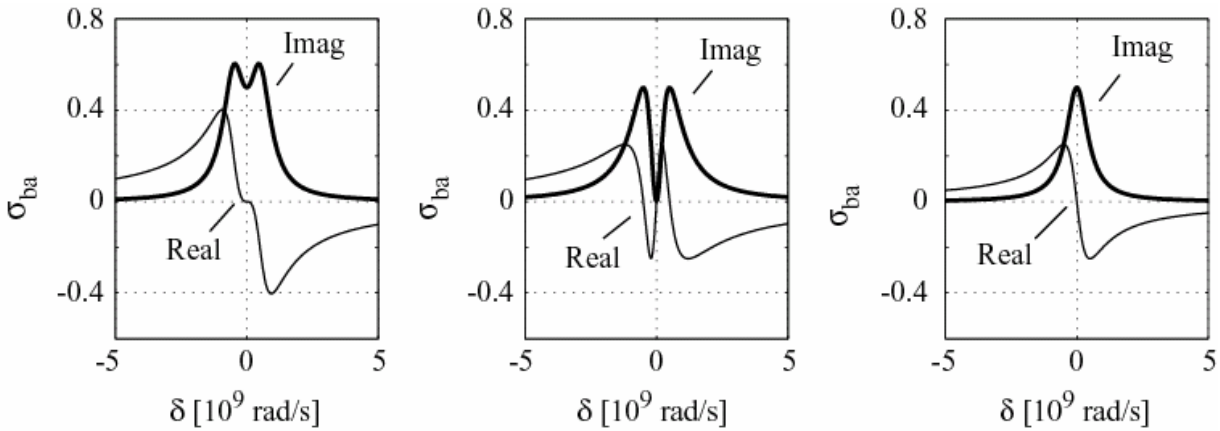
$$\chi^{(1)}_{V} = -i\frac{N\left|\mu_{ba}\right|^2}{\varepsilon_0\hbar}\frac{\left[\left(i\delta-\Gamma_{ca}\right)\left(-i\Delta_2-\Gamma_{bc}\right)+\left|\Omega_2/2\right|^2\right]}{\left(i\Delta_1-\Gamma_{ba}\right)\left[\left(i\delta-\Gamma_{ca}\right)\left(-i\Delta_2-\Gamma_{bc}\right)+\left|\Omega_2/2\right|^2\right]-\left|\Omega_2/2\right|^2\left(i\Delt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



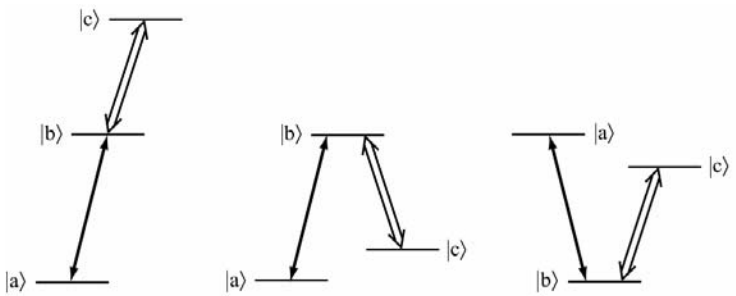
Electromagnetically Induced Transparency

Cascade System Λ System V System

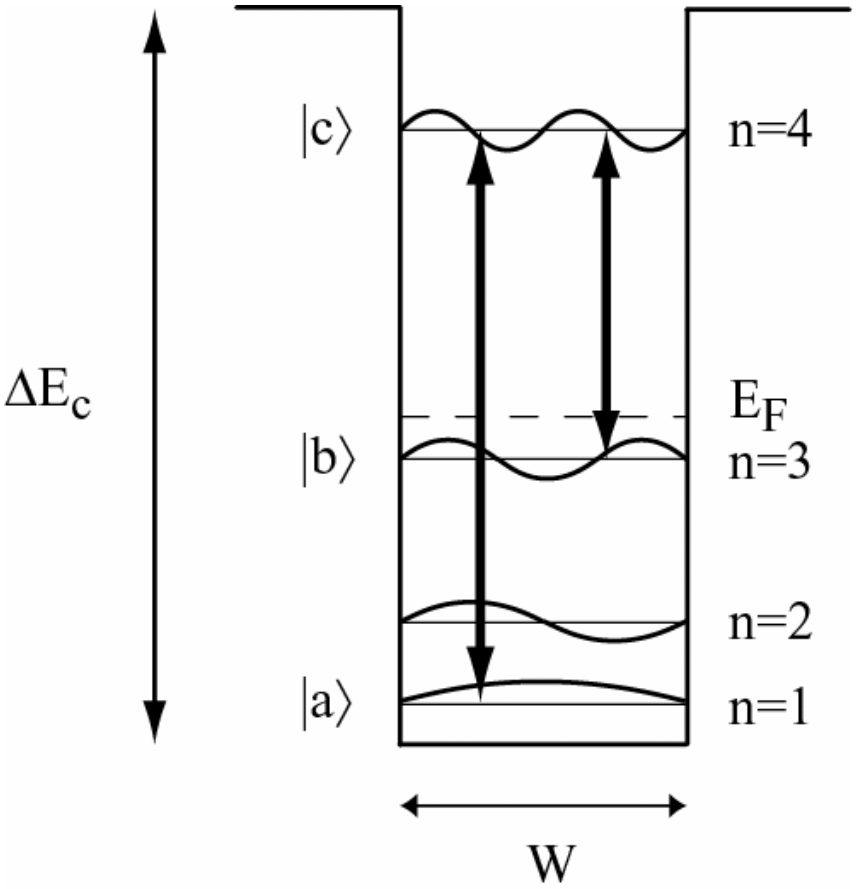
Coherent Population Trapping



$\Omega_{cb} = 1/T_1$, $\gamma_{ca} = 10^{-3}/T_1$

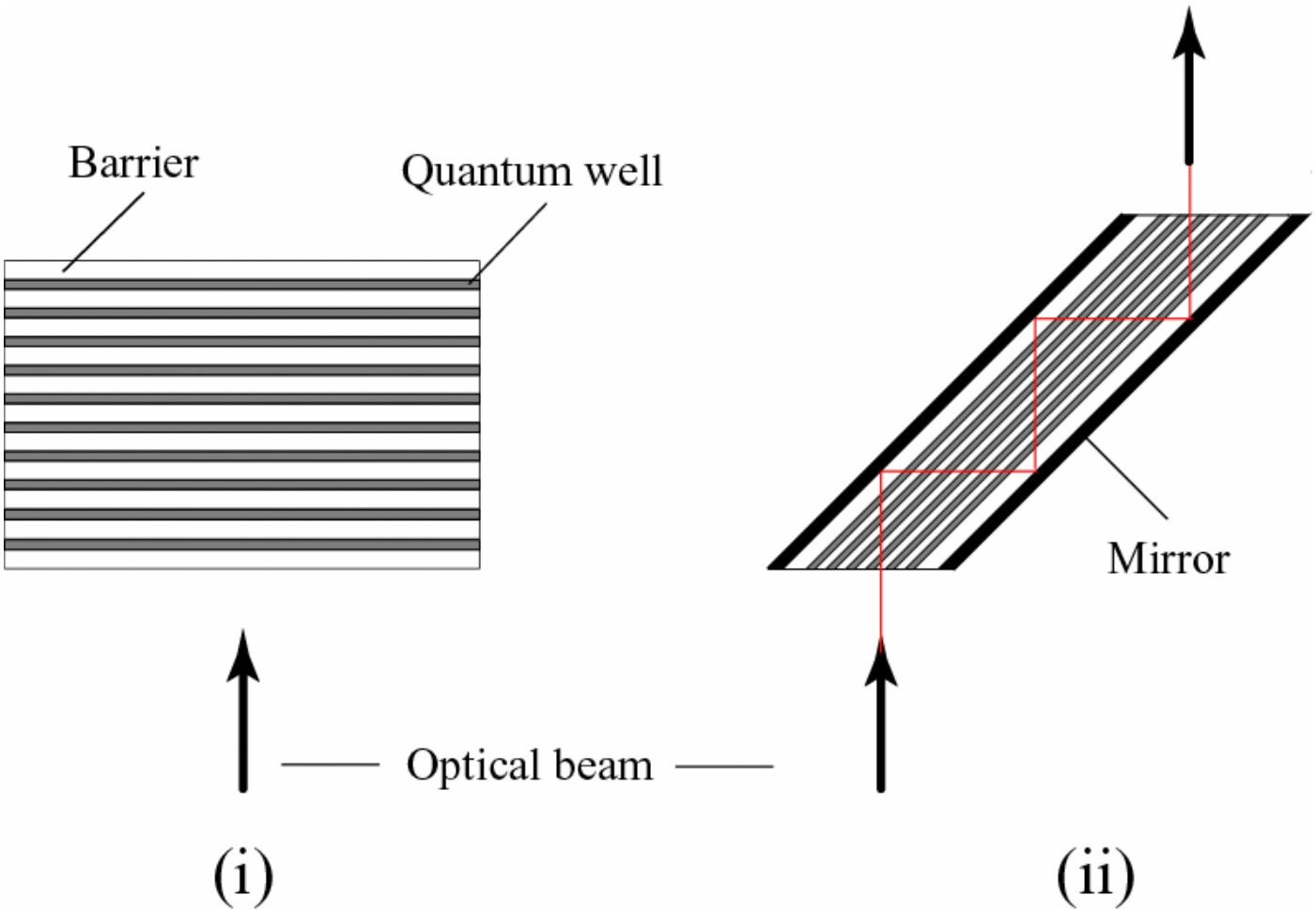


Multiple Quantum Well Structure



$$E_n = \frac{\hbar^2 \pi^2}{2m^*}\left(\frac{n^2}{W^2}\right)$$

Multiple Quantum Well Structure



Quantum Interference Studies in Quantum Well Systems

Fano interference

- Transparency window (Fano profile) due to coupling to the continuum.

J. Faist, et al. Opt. Lett. **21**, 985 (1996)

Tunnelling induced transparency

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

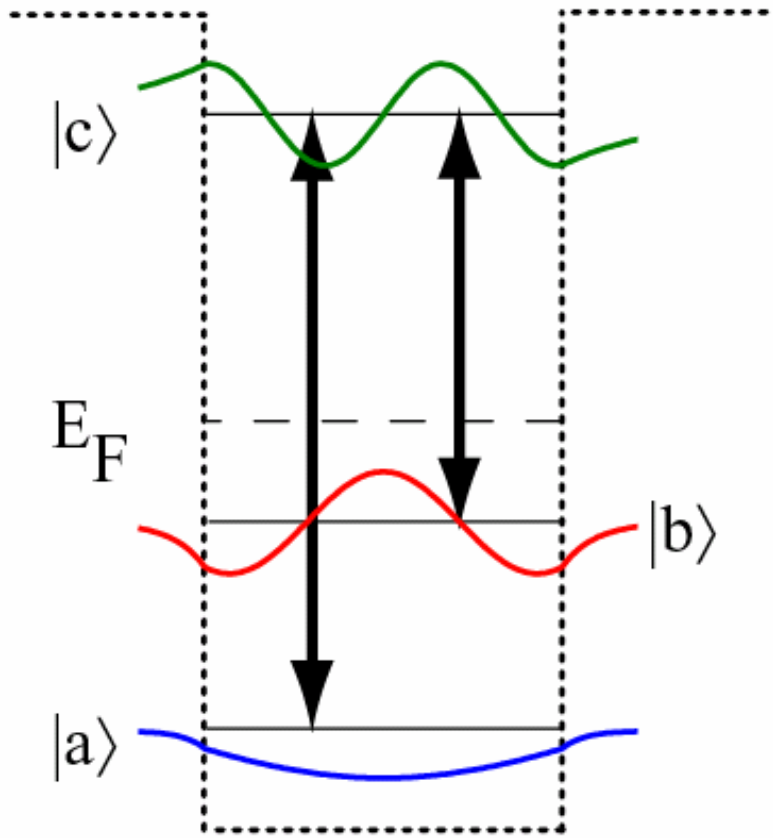
H. Schmidt et al. Appl. Phys. Lett. **70**, 3455 (1997)

EIT in a cascade system

- Cascade system in a single quantum well.

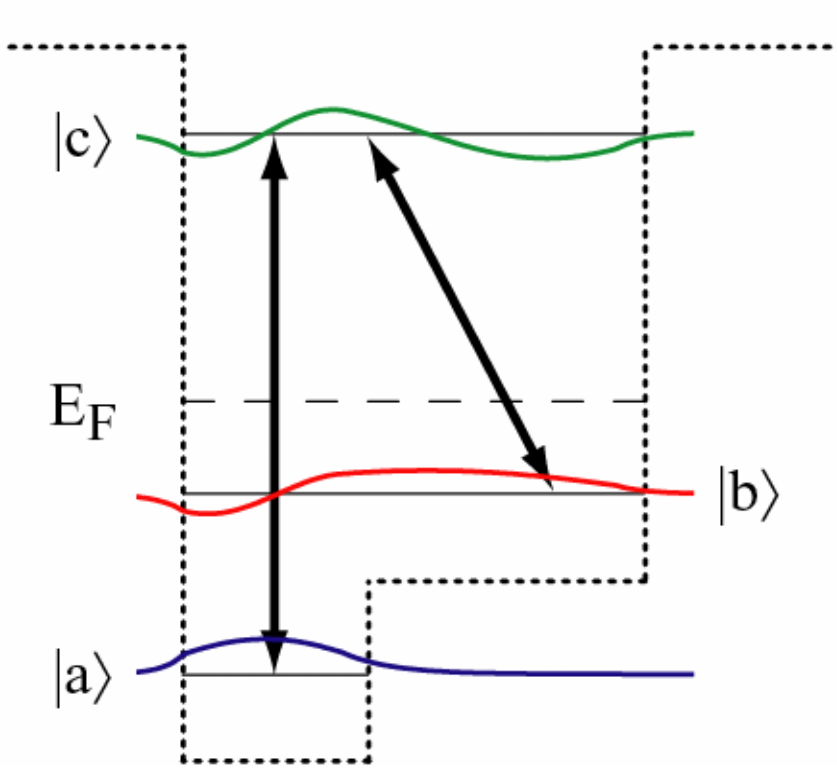
S.M. Sadeghi, S.R. Leffler and J. Mayer, Opt. Commun. **151**, 173 (1998)

Various Structures for Observing CPT



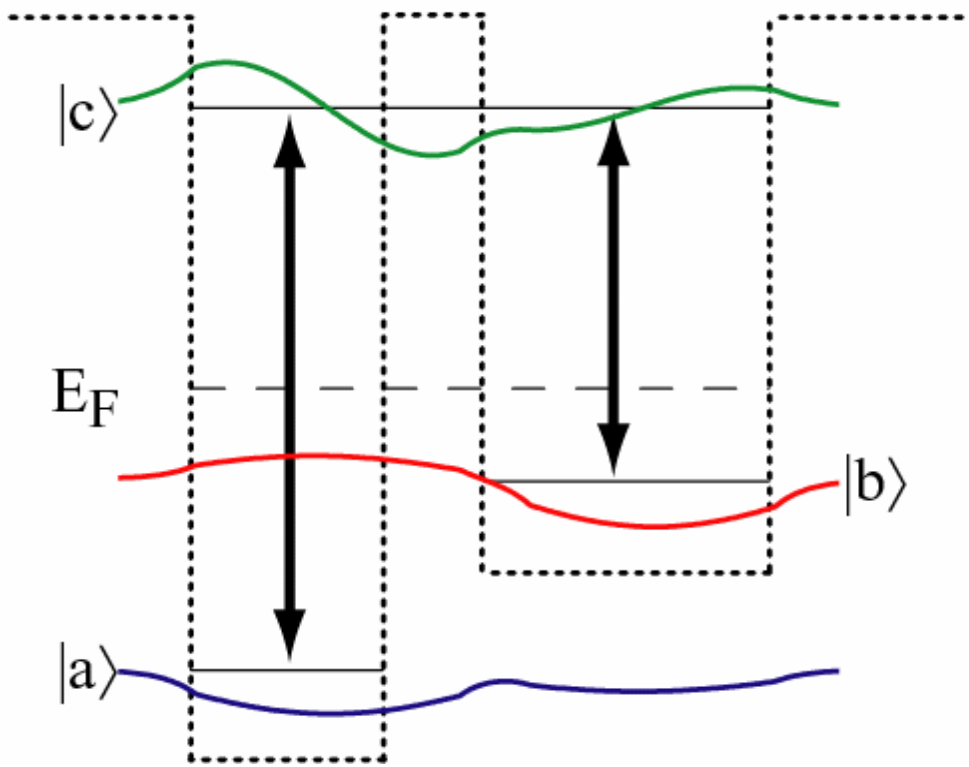
Single Well

Various Structures for Observing CPT



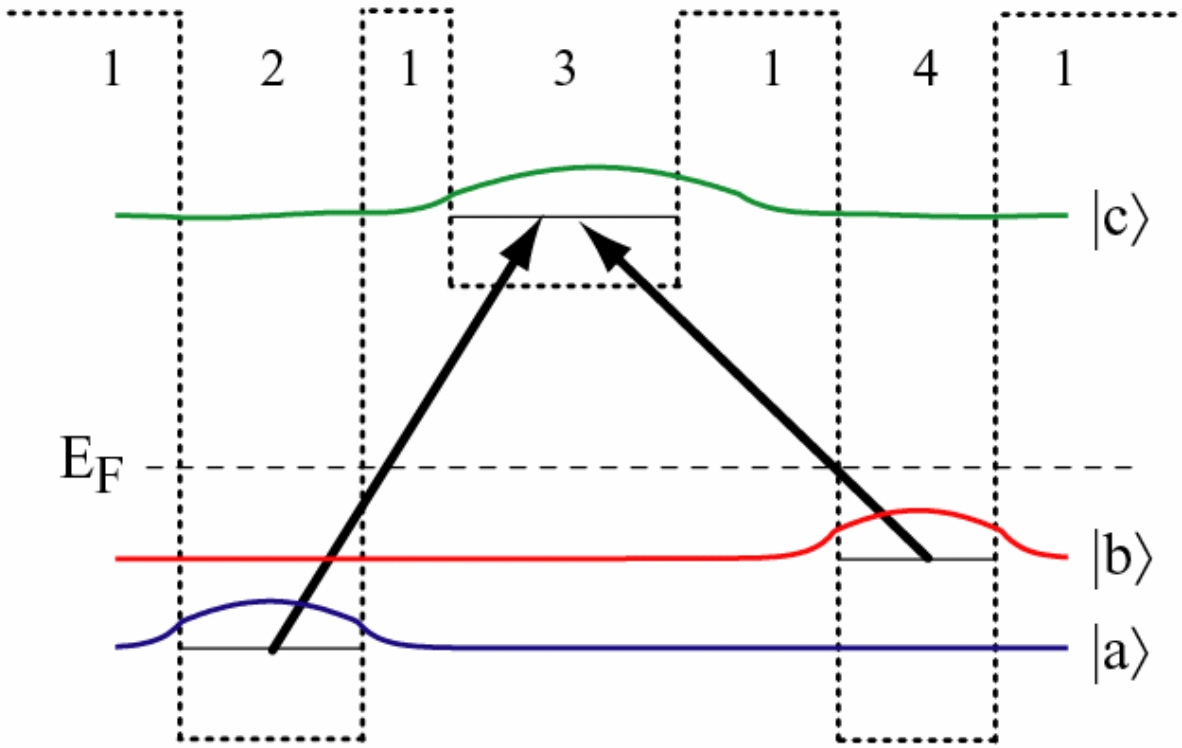
Staggered Well

Various Structures for Observing CPT



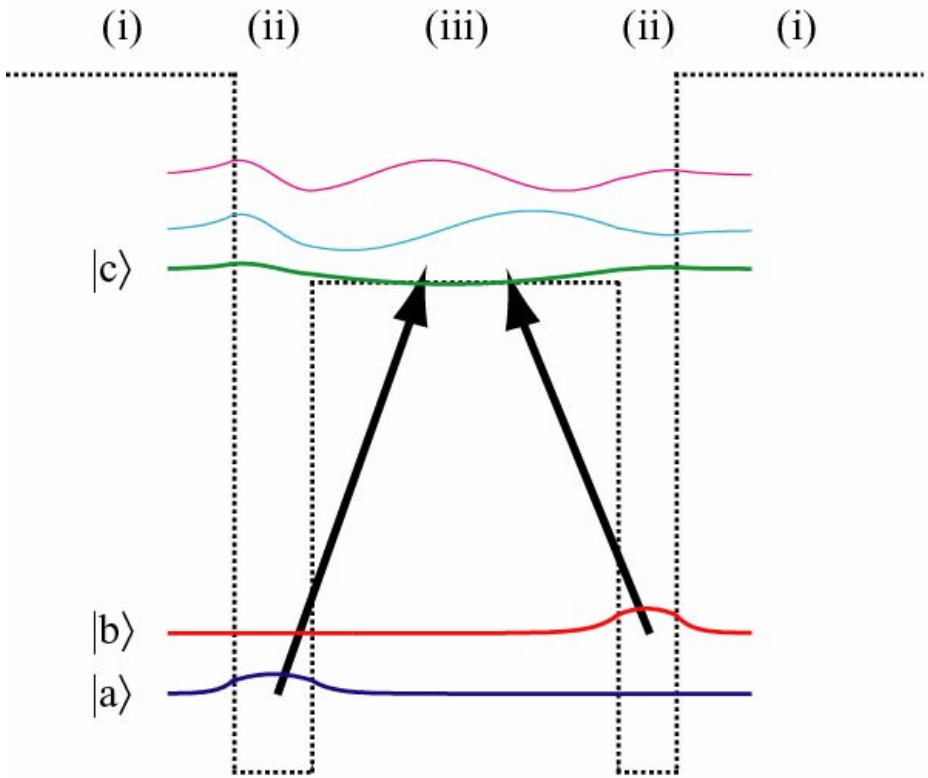
Double Well

Various Structures for Observing CPT



Triple Well

Three-Level Λ System in an Island Well



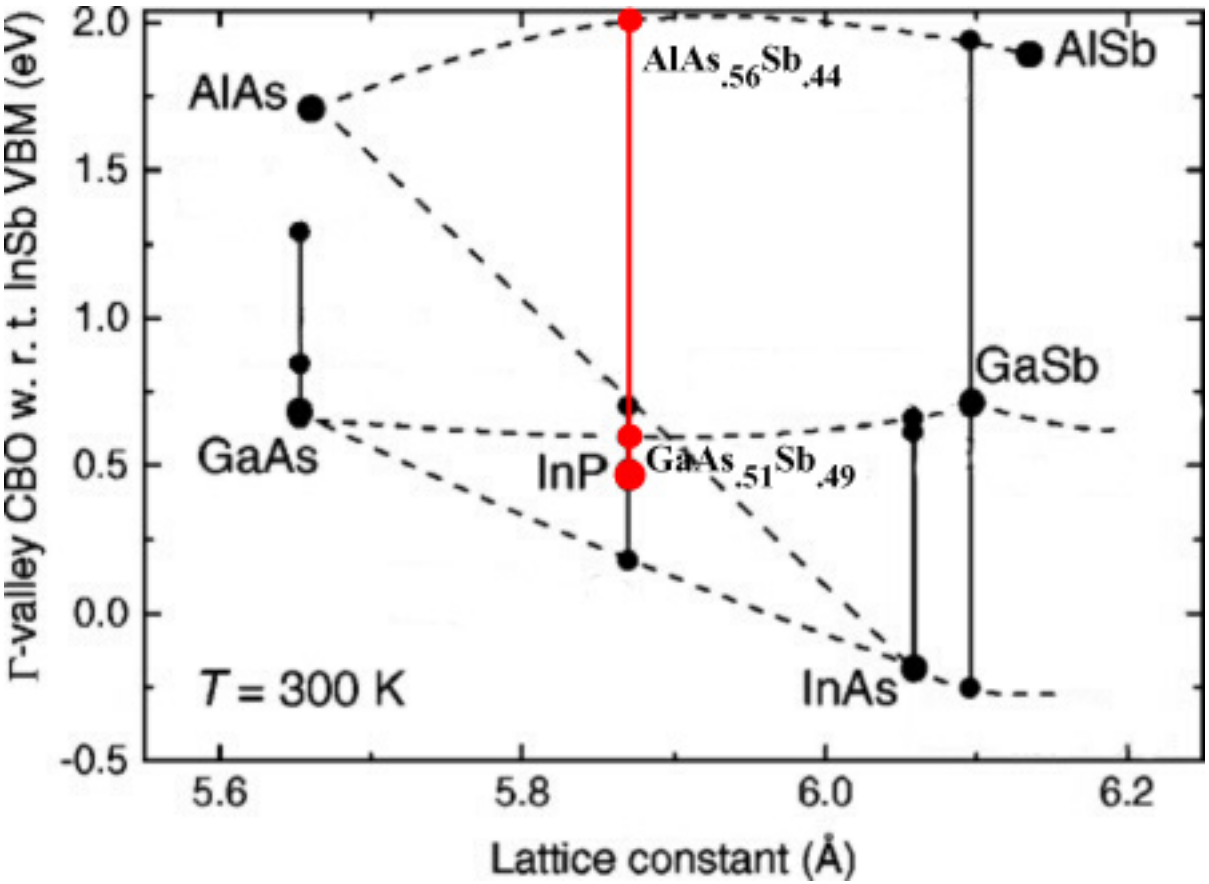
(i) $AlAs_{.56}Sb_{.44}$ barrier

(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.

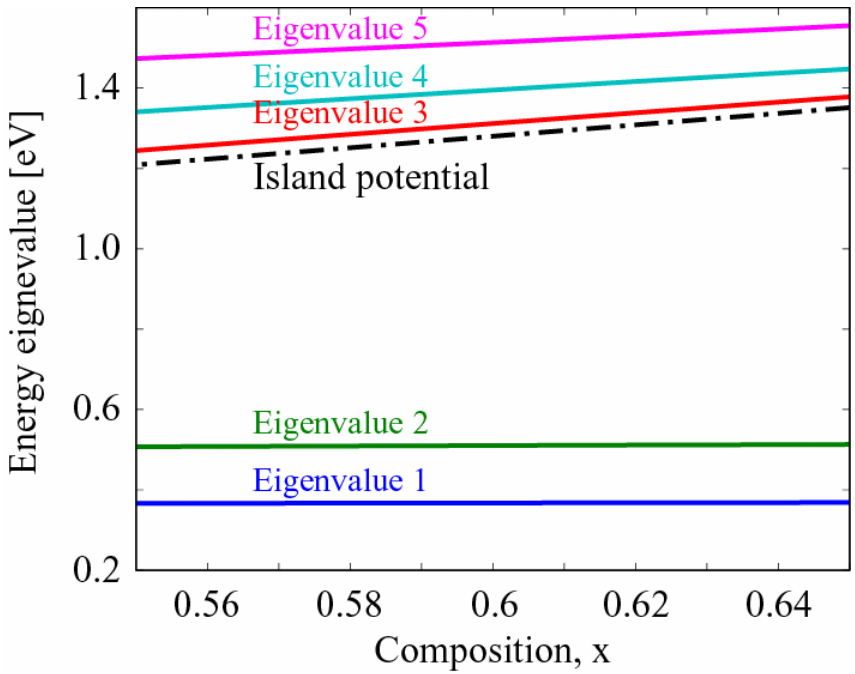
Lattice Matching GaAlAsSb to InP



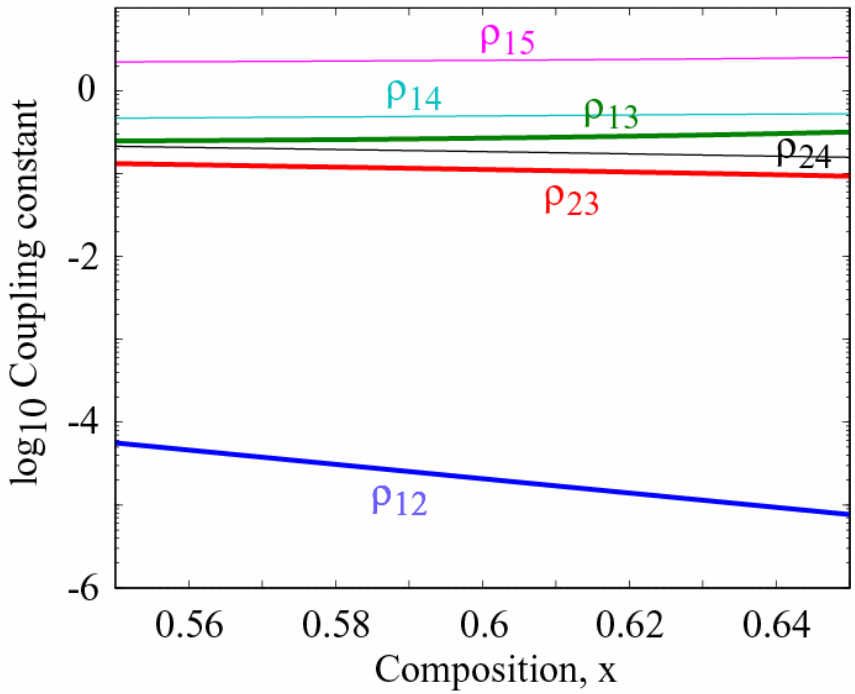
Quaternary alloy for the shallow well: $(GaAs_{.51}Sb_{.49})_{1-x}(AlAs_{.56}Sb_{.44})_x$

Design of the Shallow Well

Eigenvalues of the island well

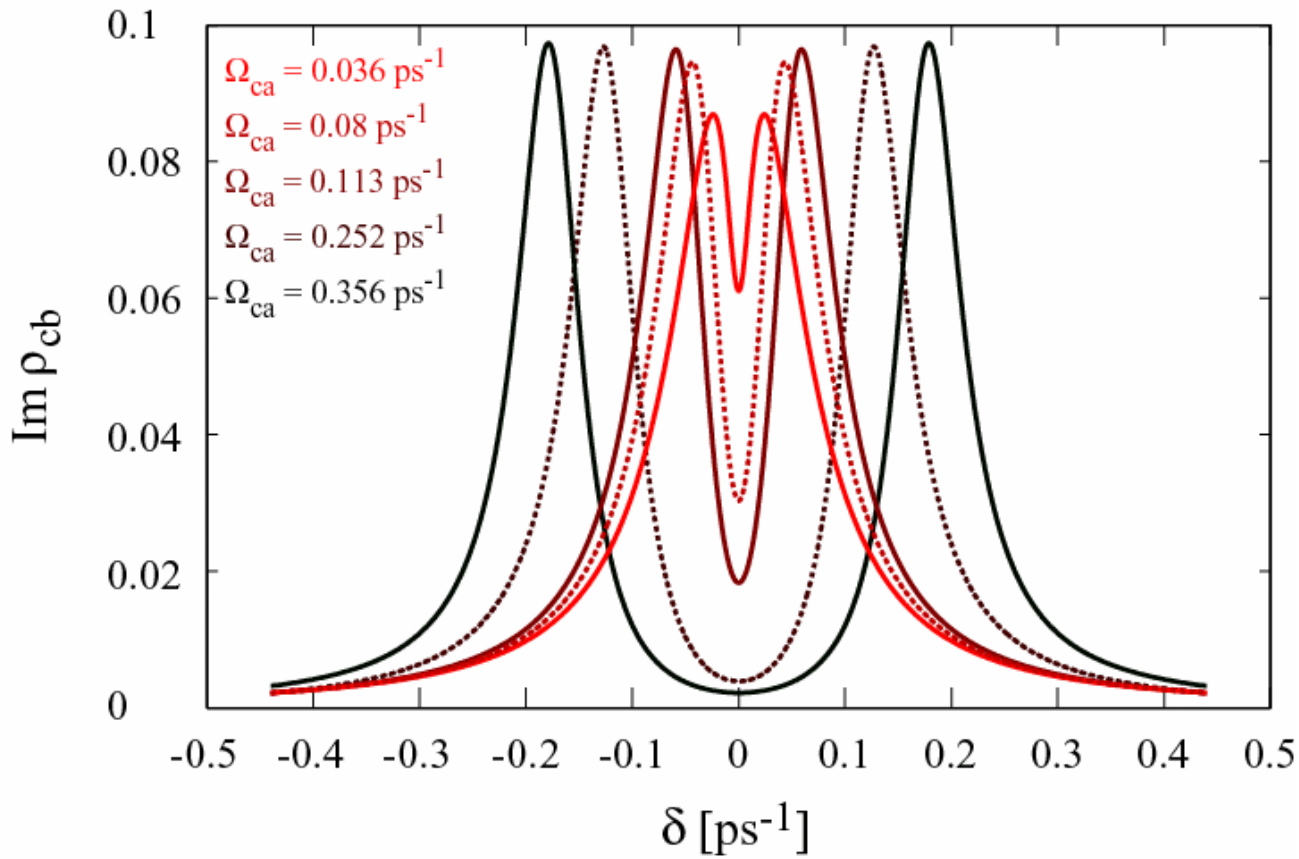


Coupling rates between various levels



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

Simulation Results



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