Magneto-Exciton in Single and Coupled Type II Quantum Dots

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Overview

- Introduction I: self-assembled quantum dots
- Introduction II: what are type-II quantum dots?
- Theoretical model
- Planar quantum dots
- Dots of finite height
- Vertically coupled quantum dots
- Conclusion

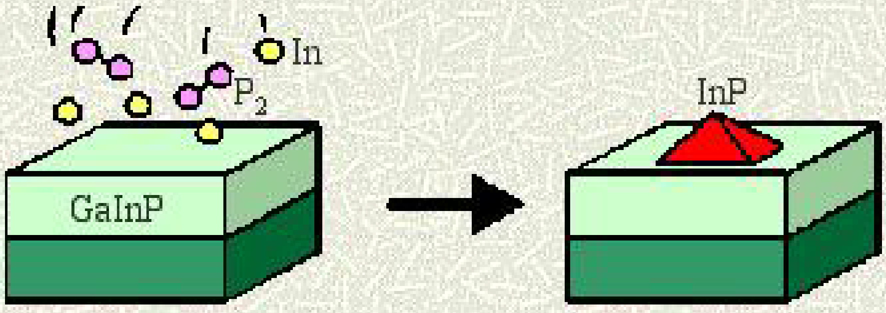
Introduction I: self-assembled quantum dots

Necessary ingredients:

2 semiconductor materials with a substantially different lattice parameter, e.g.

InP : a ~ 5.869 Å and GaInP : a ~ 5.653 Å (mismatch ~ 3.8%)

MBE growth



Result

lattice mismatch ⇨ strain fields ⇨ formation of islands

⇩

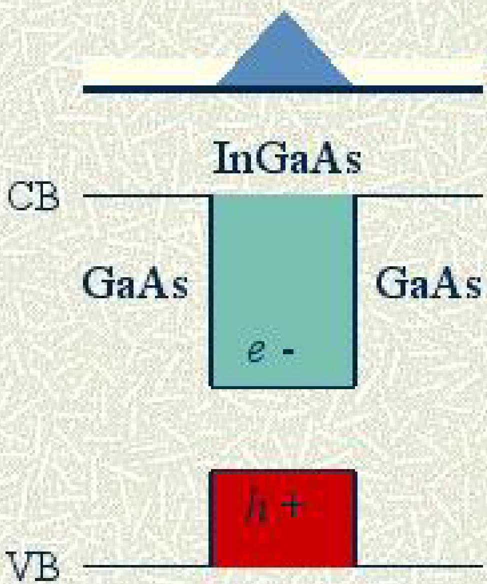
self-assembled quantum dots

Introduction II: what are type-II quantum dots?

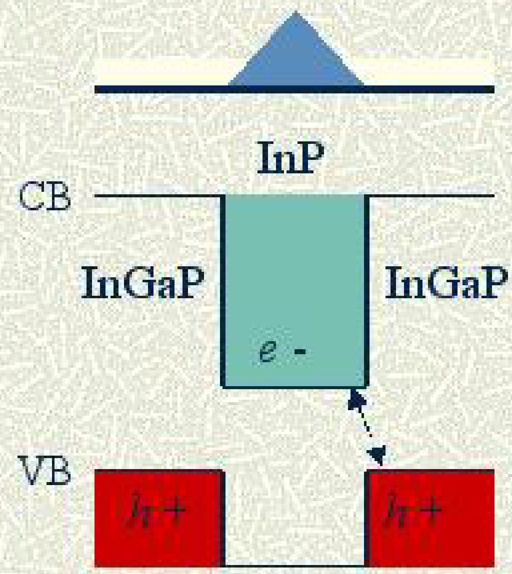
vs.
Type-I : electron and hole both located in the dot
Type-II : one of the carriers located in the barrier material

Band alignment schemes (two-band model)

Type-I



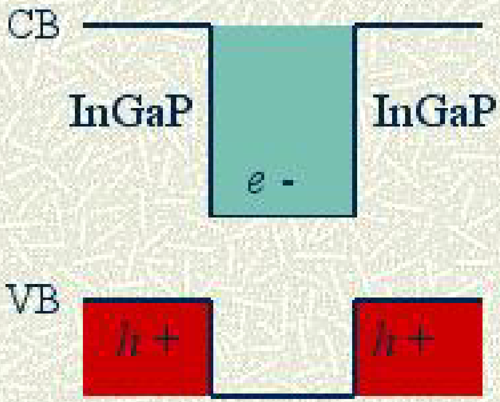
Type-II



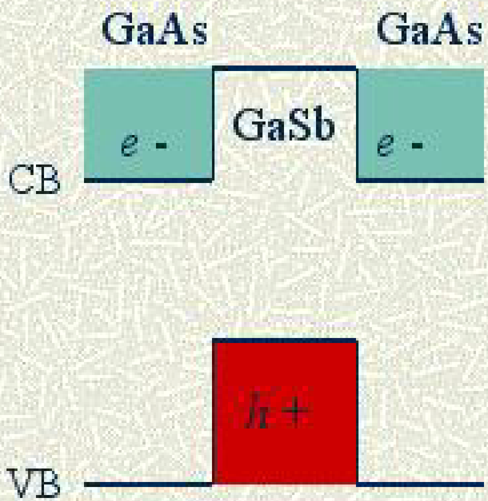
⇨ spatially indirect exciton

• Different possible type-II systems

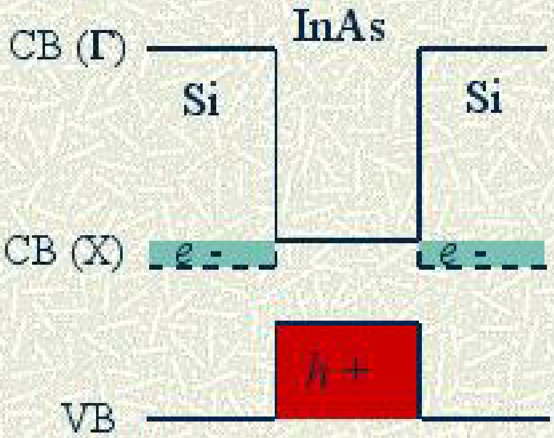
electron in the dot, hole outside
e.g. InP/GaInP dots



hole in the dot, electron outside
e.g. GaSb/GaAs dots

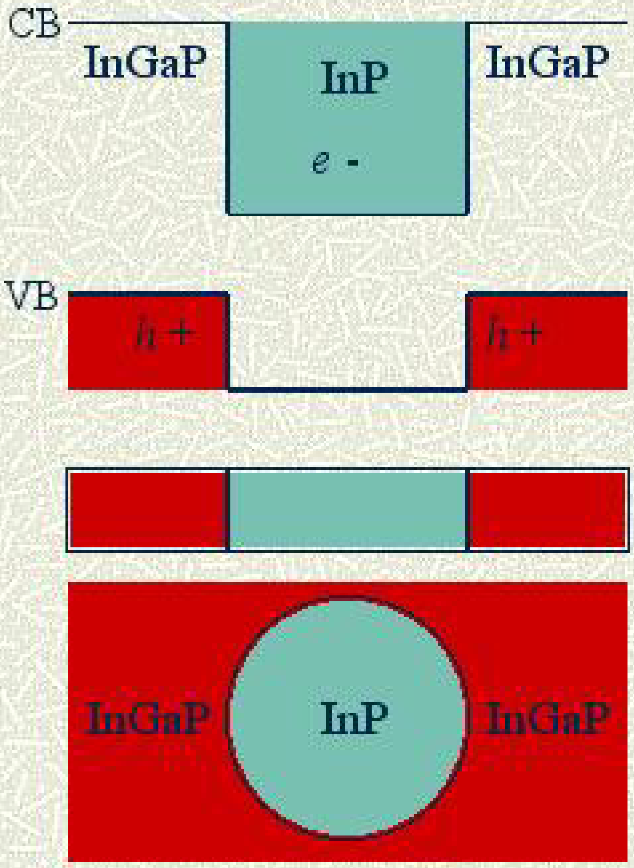


InAs/Si dots



Theoretical model

Study of a *single* exciton in a quantum *disk*

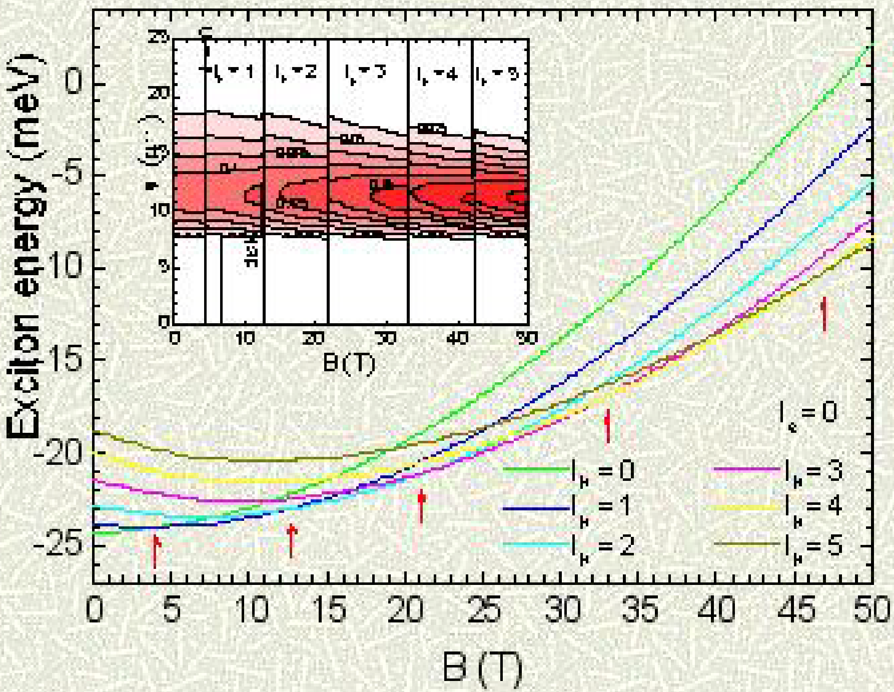


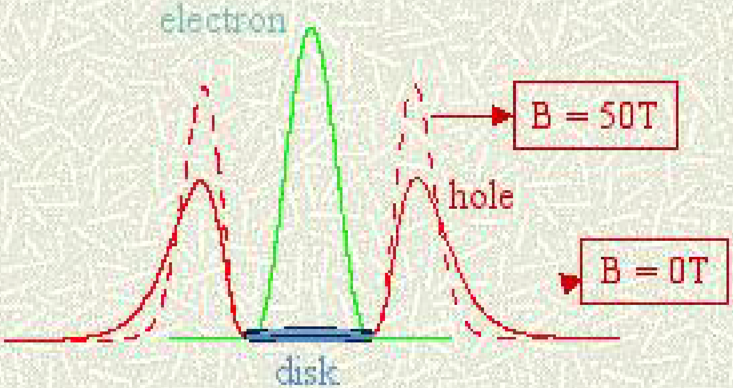
- no strain effects ⇒ hole is confined to the disk, only due to the Coulomb interaction to electron
- no a priori knowledge about the size of the hole wavefunction ⇒ difficult to choose good basisfunctions for the expansion of the hole wavefunction
- Our solution: we solved the Hartree-Fock equations on a grid, allowing very flexible solutions (in principle of arbitrary shape)
- typical parameters in our study are those of the InP/GaInP system:

Planar quantum dots

- no inclusion of z-direction
- the hole is forced to sit at the radial boundary of the dot

Results for $R = 8nm$ and $V_h = -50meV$

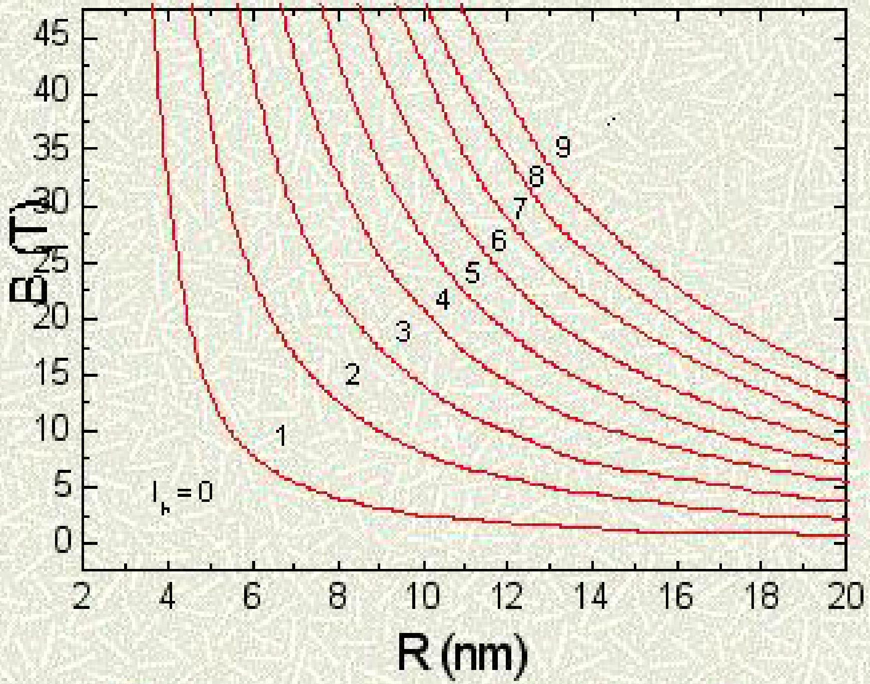




- angular momentum transitions with increasing magnetic field

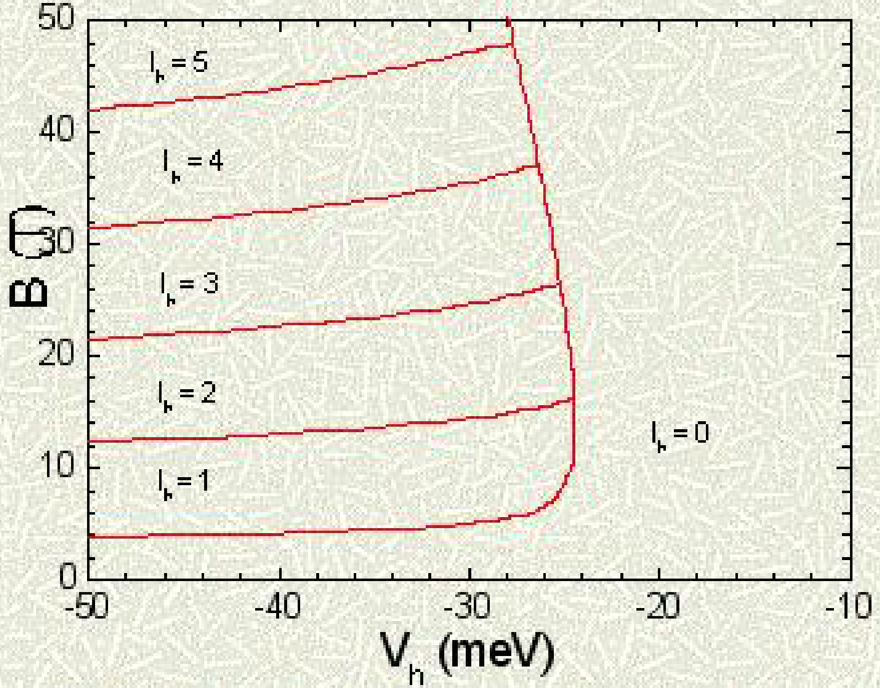
• Phase diagrams of the angular momentum transitions

❖ (B,R) - diagram



⇒ Transitions occur faster for higher R

❖ (B,V_h) - diagram

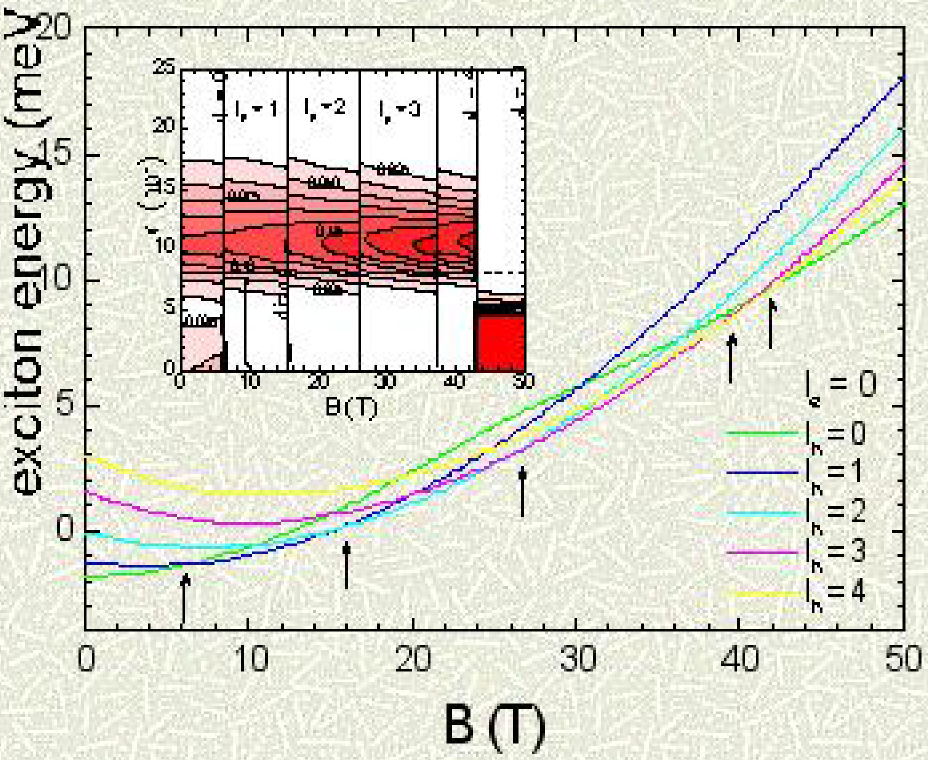


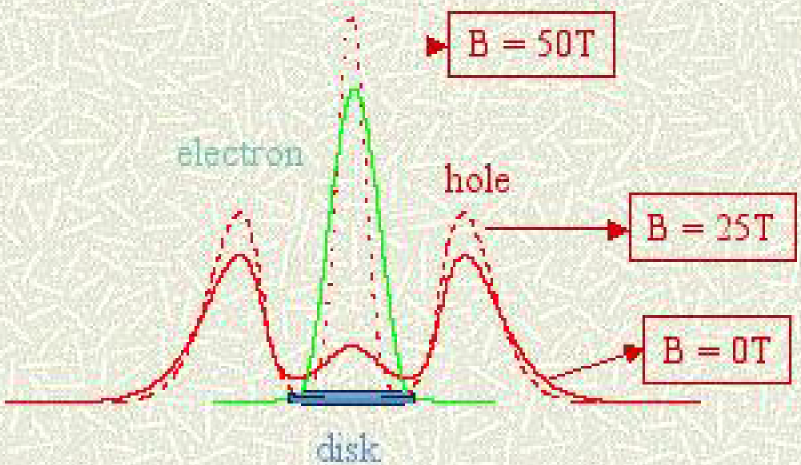
⇒Up to $V_h \approx -24.5$meV no angular momentum transitions

⇒system is still type I

• Re-entrant behaviour

Result for $R = 8nm$ and $V_h = -27meV$

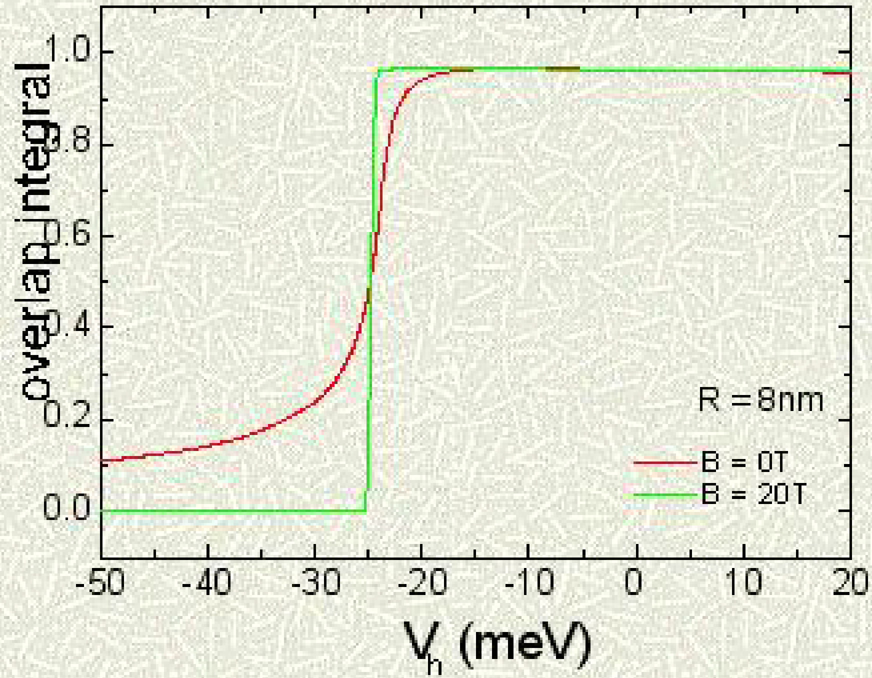


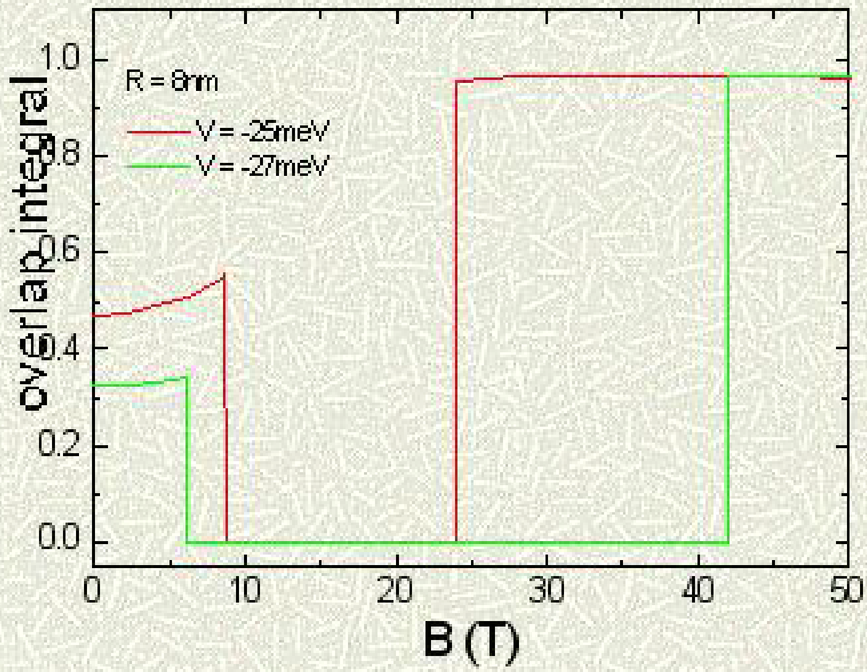


- re-entrance of the $l_h = 0$-state as the ground state
- accompanied by jump of the hole into the disk (due to interplay between magnetic field, confinement potential and Coulomb interaction)

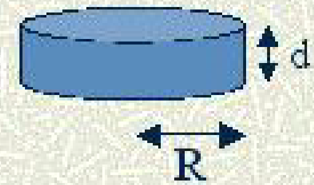
• Oscillator strength

Proportional to



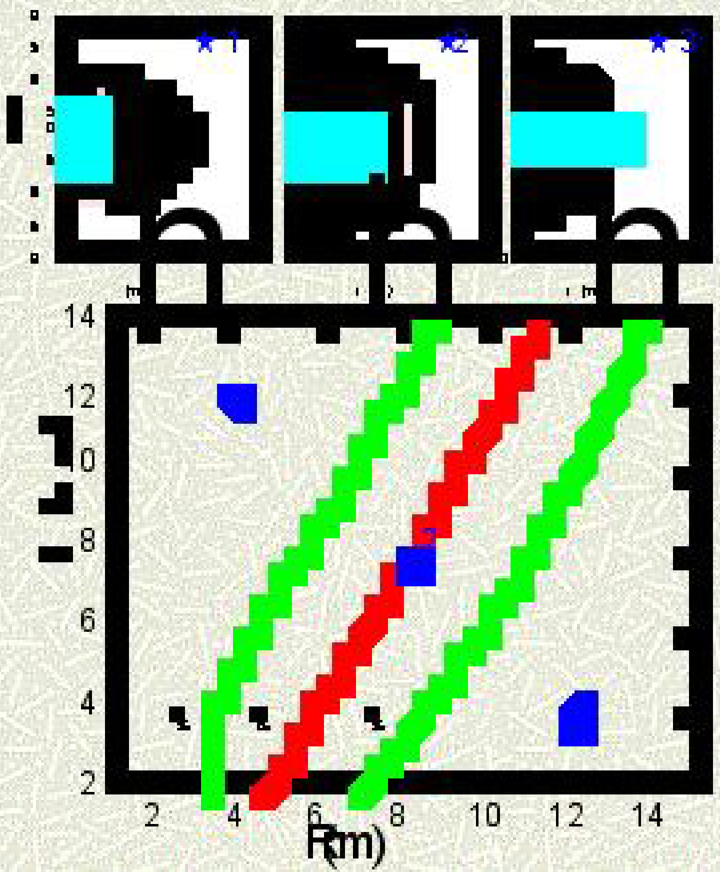


- angular momentum transition induces drastic decrease of the probability for recombination of the exciton
- strong quenching or disappearance of the PL spectrum in photoluminiscence experiments can be expected



Dots of finite height

- the z-direction is included
- the hole can sit: - at the radial boundary of the dot
  - above/below the disk



- Study of the influence of the disk parameters d and R (at $B = 0T$)

Distinguish between 2 regimes:

- disk-like regime: $d << 2R$

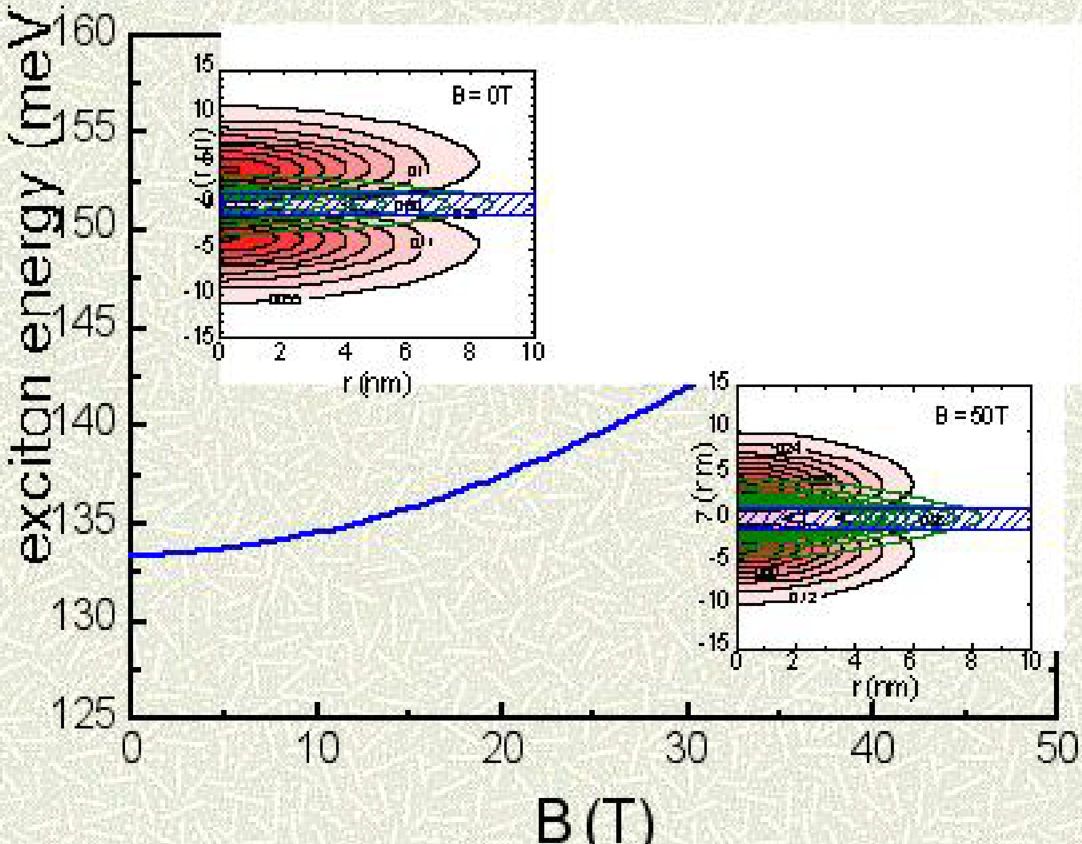
(★3)

- pillar-like regime: $d >> 2R$

(★1)

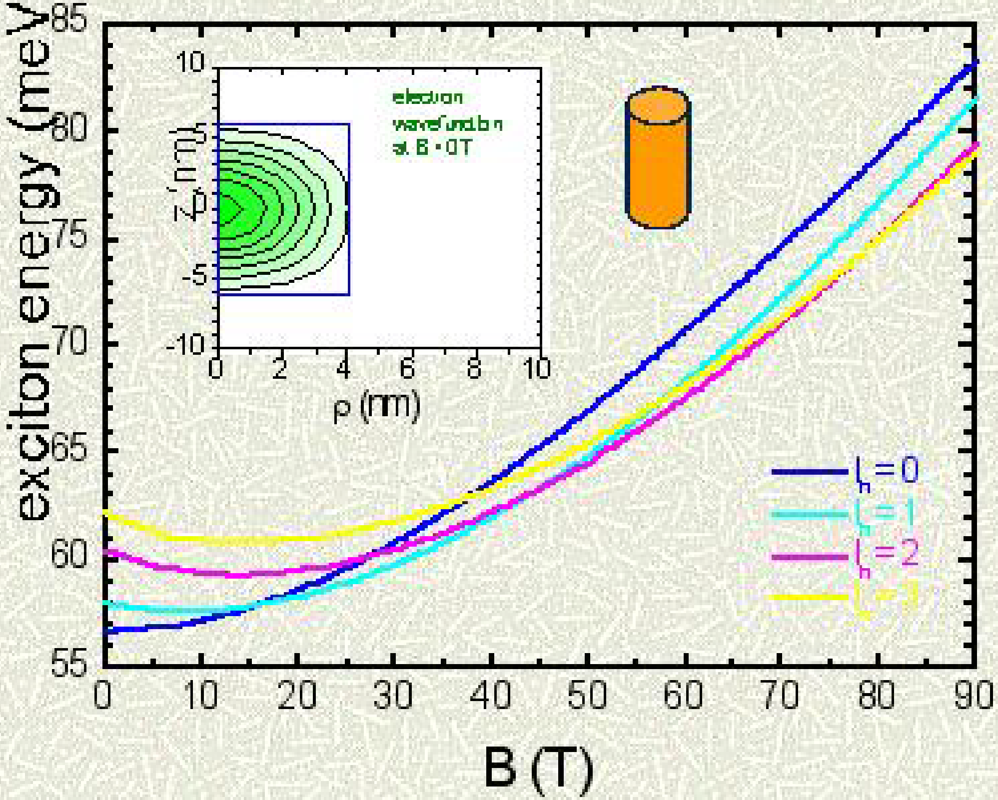
• Disk-like system : *d = 2nm, R = 10nm*

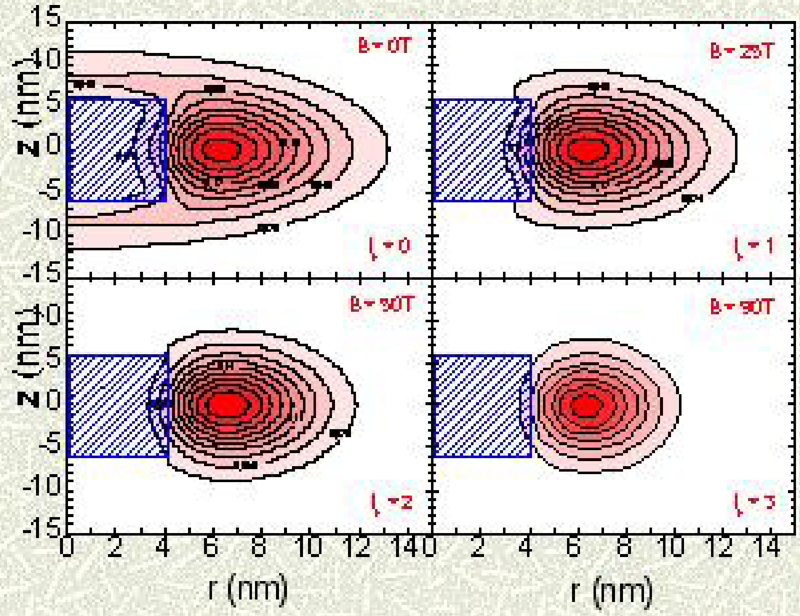
Exciton energy as a function of the magnetic field



- ❖ magnetic field squeezes the wavefunctions in the radial direction
- ❖ increase of the overlap
- ❖ increase of the total energy

• Pillar-like system : $d = 12nm, R = 4nm$



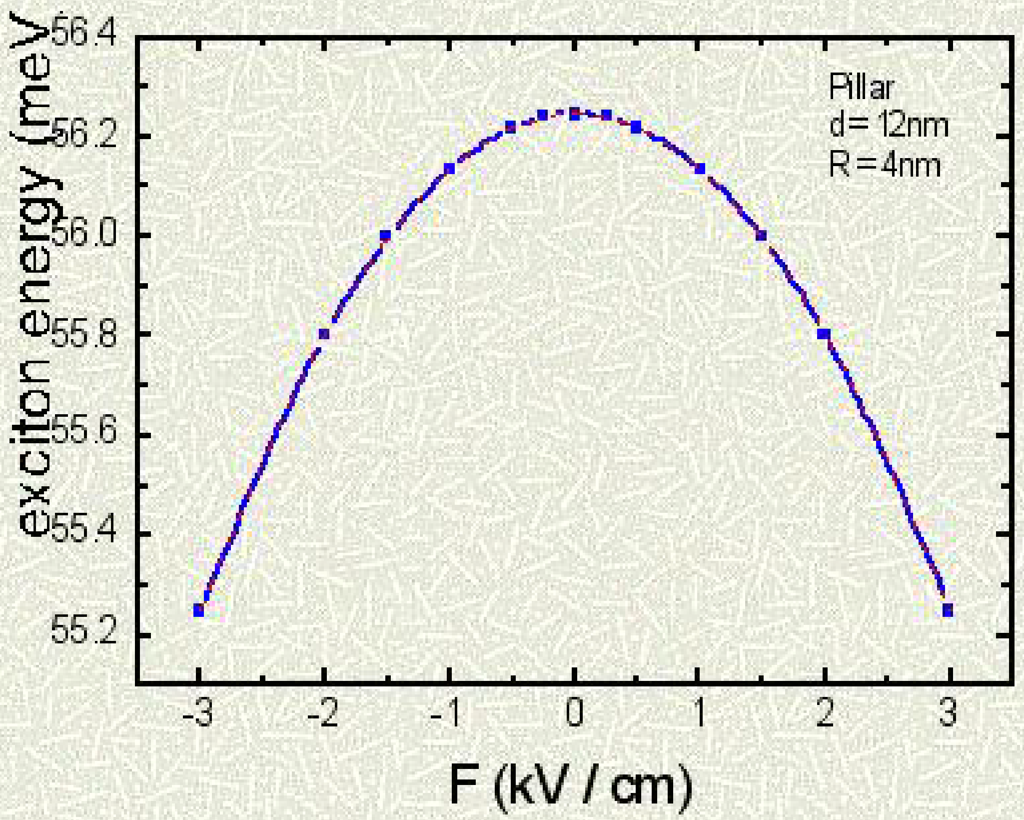


❖ the hole is sitting at the radial boundary of the quantum disk

❖ appearance of angular momentum transitions

• Electric field dependence

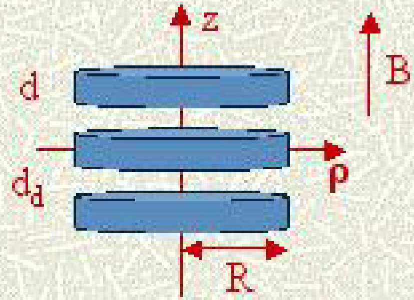
❖ Stark shift



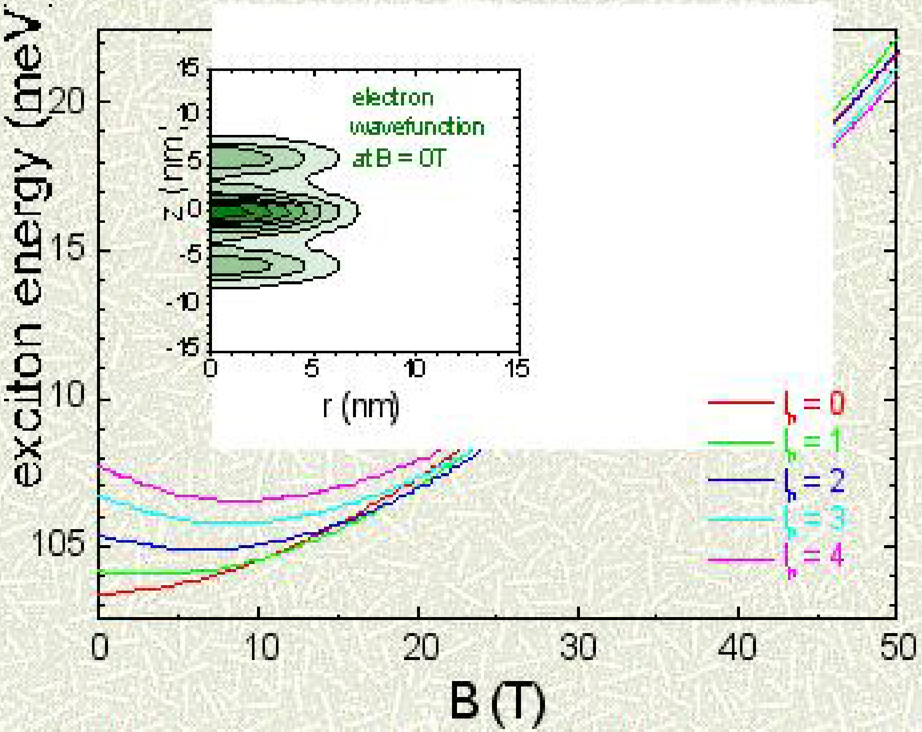
p = built-in dipole moment,
β = polarizability

Vertically coupled quantum dots

- Three vertically coupled dots
  - ⇒extra parameter to vary: interdot-distance d_d
  - ⇒easier realization of the pillar-like system



- small d_d

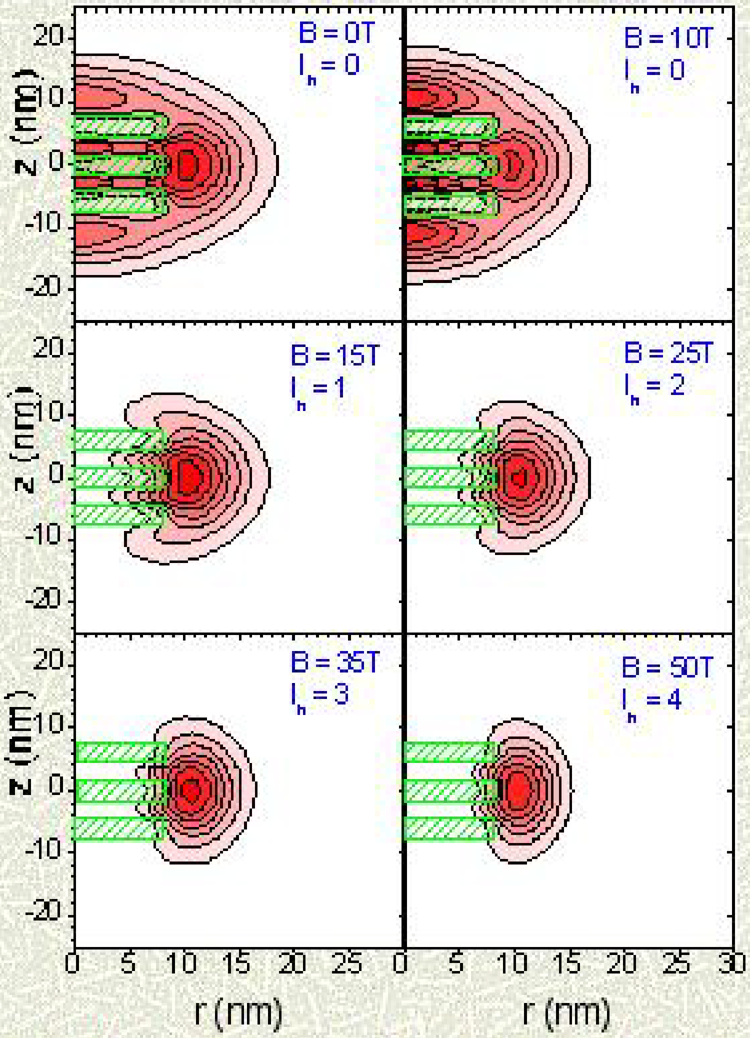


Result for $R = 8nm$, $d = 3nm$ and $d_d = 3nm$

- total stack height is 15nm
- angular momentum transitions with increasing magnetic field (as in the pillar-like system)
- electron is mainly located in the middle dot

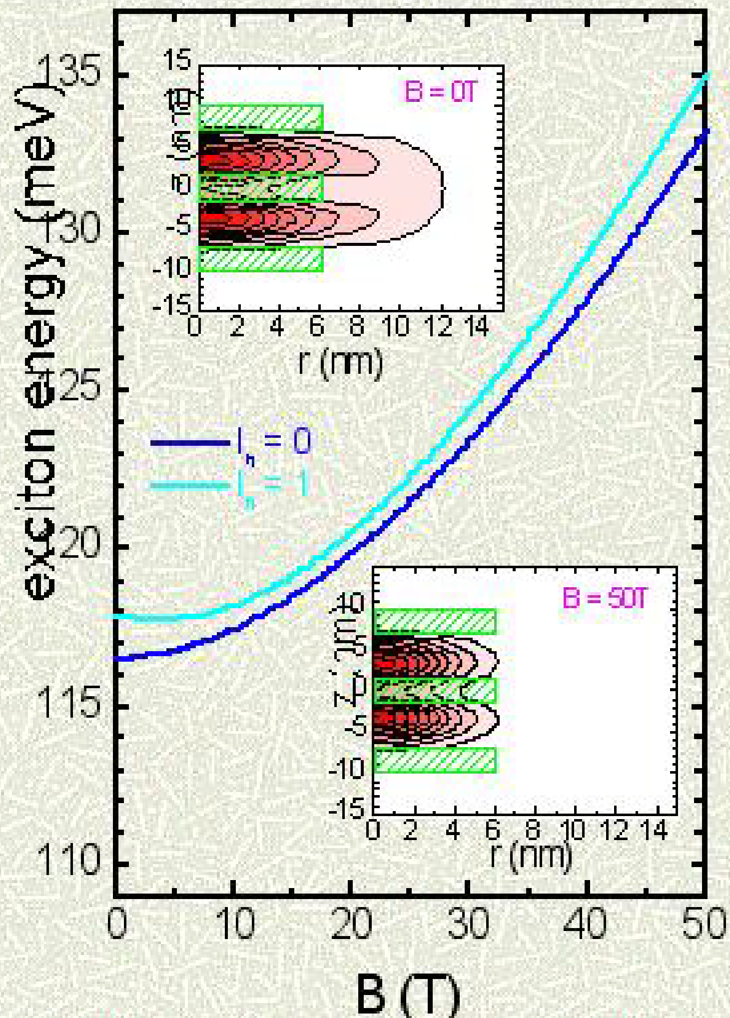
Total stack height (15nm) is comparable to disk diameter (16nm) ⇒pillar-like system

What happens with the holewavefunction ?



- ❖ B = 0T : hole is sitting mainly at radial boundary and partially between the dots
- ❖ B = 10T : the magnetic field pushes the hole more between the dots (squeezing in radial direction)
- ❖ B = 15T : not enough space between the dots
  - ⇒ hole jumps to higher l_h-state
  - ⇒ hole is pushed to radial boundary
- ❖ B = 25T, 35T, 50T : jumps to respectively l_h = 2, 3, 4

❖ large d_d



Result for $R = 8nm$, $d = 3nm$ and $d_d = 5.5nm$

- ❖ increasing the interdot-distance increases the available space for the hole between the disks
- ❖ magnetic field pushes the hole between the disks
- ❖ transition to regime without angular momentum transitions (like the disk-like regime)

Conclusions

- We studied the properties of anexciton in a type II quantum dot. Model: quantum disk, 2 band model (EMA), no strain effects using a Hartree-Fock mesh calculation
- Angular momentum transitions with increasing magnetic field:
  - Planar dots (also a re-entrant behaviour was found)
  - Dots of finite height, if $d >> 2R$ (pillar-like system)
  - 3 vertically coupled dots with small interdot distance
- Electric field effect: Stark shift as a function of the electric field

  Single dot: parabolic behaviour of the energy around $F = 0 kV/cm$
- Our study was based on a system with the electron located in the disk, and the hole outside, in the barrier material. However, the same physics will be present in the system with the electron outside and the hole inside the dot.