Theory of vertical and lateral Stark shifts of excitons in InGaAs quantum dots

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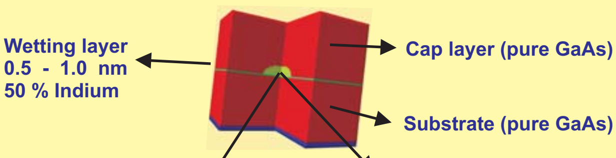
Motivation: The shape and alloy composition of self-assembled InGaAs quantum dots are difficult to determine directly from the experiment.

Goal: Prediction of shape and alloy profile of single InGaAs quantum dots by investigating the shift of the single exciton transition energy under external electric fields applied in vertical and lateral directions.

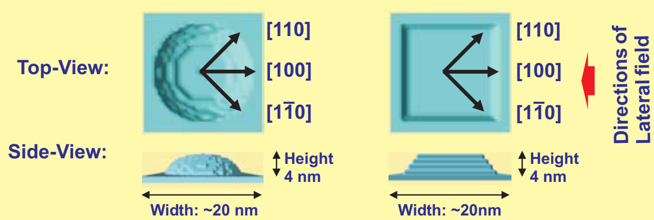
Method of calculation:

- Selfconsistent multiband k.p Kohn-Sham-equations
- 3D strain and piezoelectric fields fully included
- Electron-hole Coulomb interaction included
- External electric and magnetic fields in arbitrary directions

Structure:



InGaAs quantum dot:

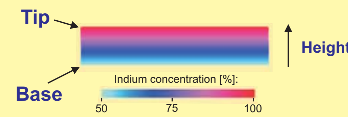


Alloy profiles:

In this work two different alloy profiles are considered:

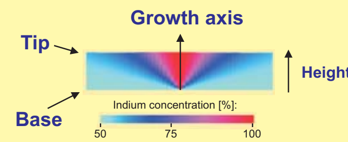
Linear profile:

Indium content rises from 50% (wetting-Layer) to 100% at the tip of the QD. Laterally homogenous



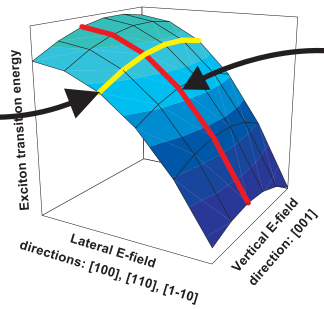
Radial profile:

Indium content depends on angle to growth axis. This profile leads to an inverted pyramid of high Indium concentration. Indium content rises from from 50% (wetting-Layer) to 100% in the center of the QD.



Contourplot of an STM measurement of a cleaved surface showing a single InGaAs quantum dot. (Tersoff et al. Phys. Rev. Lett. 84, p.334 (2000))

Stark-shift of exciton energy



Exciton energy as function of vertical electric field with fixed lateral field as a parameter

Exciton energy as function of lateral electric field with fixed vertical field as a parameter

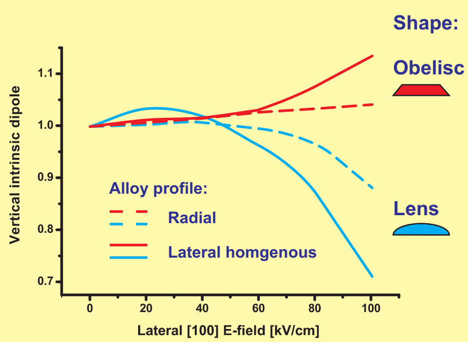
Parabola fit to Stark curve:

$$E(F) = E_0 + pF + cF^2$$

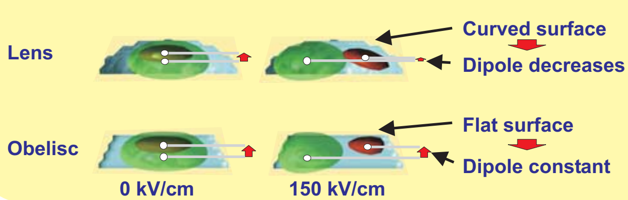
Intrinsic dipole (p) — Polarizability (c)

Indicator for dot shape:

Shape-specific change of the intrinsic vertical dipole with increasing lateral field!

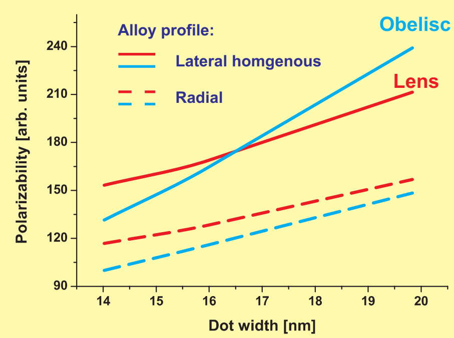


Relative change of vertical intrinsic dipole (dipole at zero lateral field normalized to one)

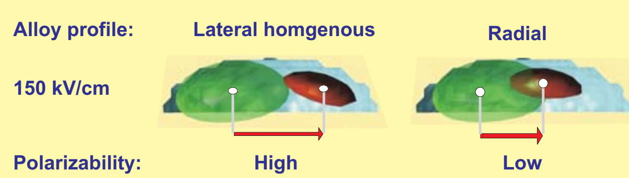


Indicator for alloy profile:

Lateral polarizability is strongly dependent on width and lateral alloy profile of the QD:



Change of lateral polarizability with QD width for radial and laterally homogenous alloy profiles.



Conclusion:

- Change of intrinsic dipole with lateral electric field indicates shape of quantum dot
- Polarizability for lateral electric field indicates lateral alloy profile of quantum dot

Experiments with vertical and lateral electric fields are well suited to examine shape and alloy profile of InGaAs quantum dots