Stacked layers of sub-monolayer InAs in GaAs:

COMSOL CONFERENCE 2014 CAMBRIDGE

Zero- or two-dimensional?

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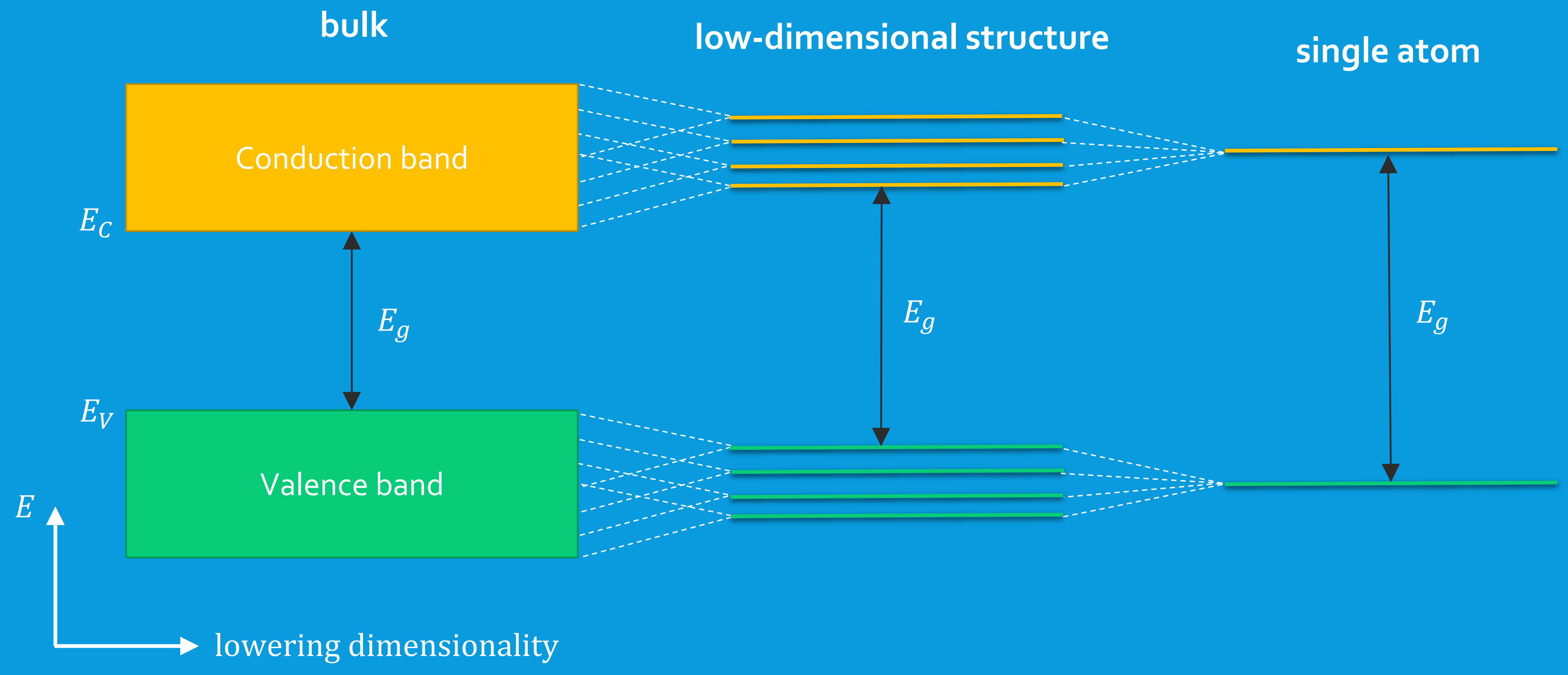
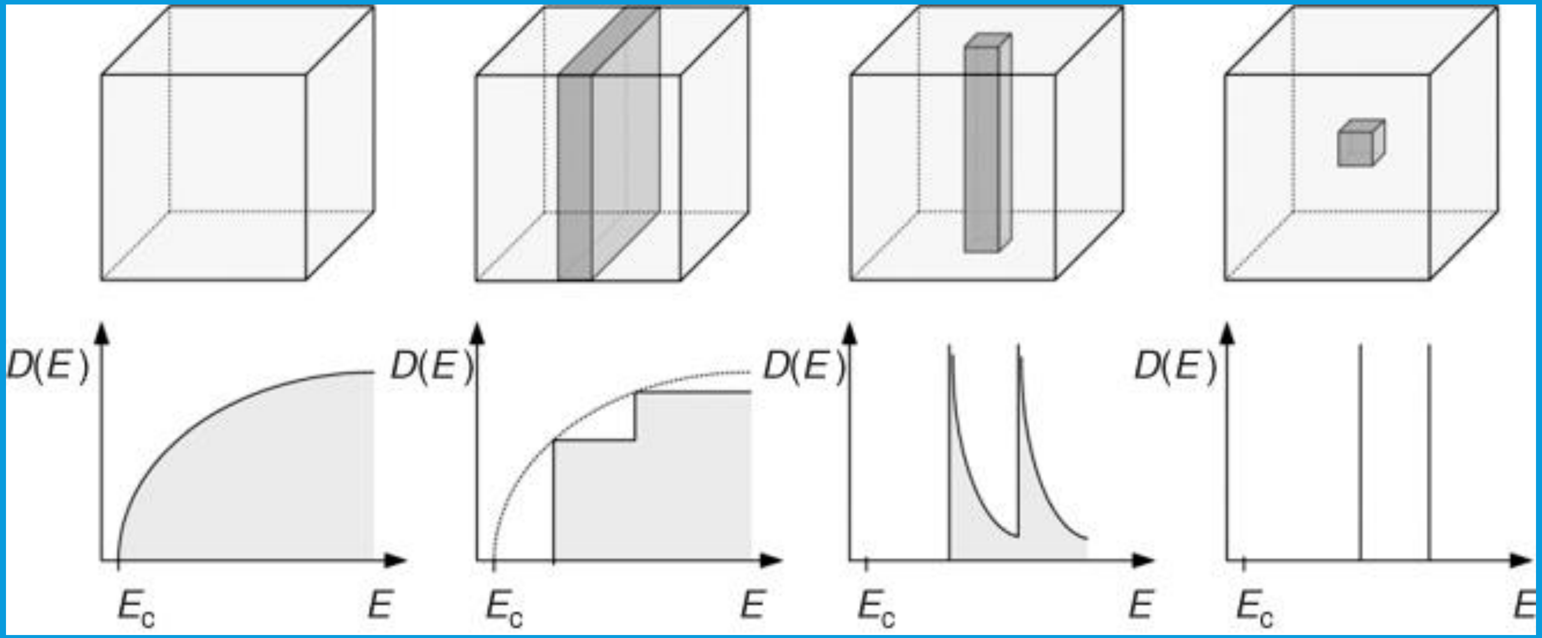
Low-dimensional nanostructures



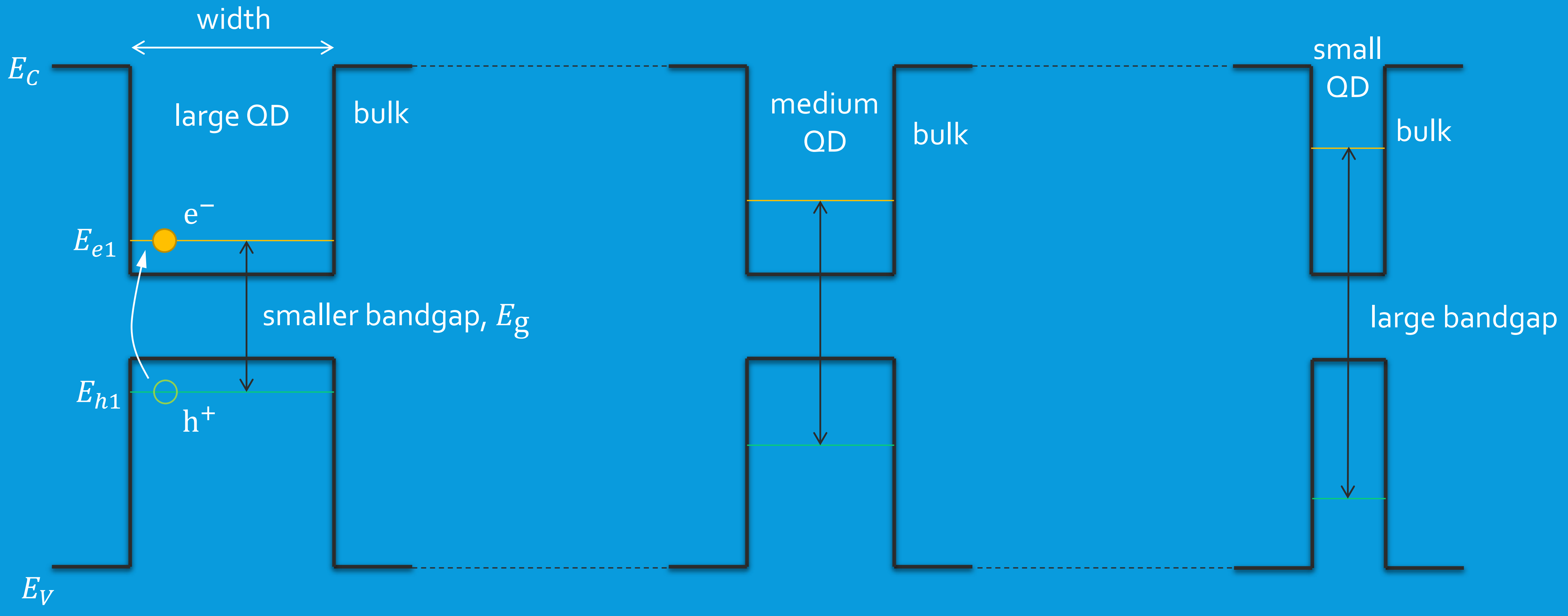
Low-dimensional nanostructures

bulk	quantum well	quantum wire	quantum dot



3D	2D	1D	0D

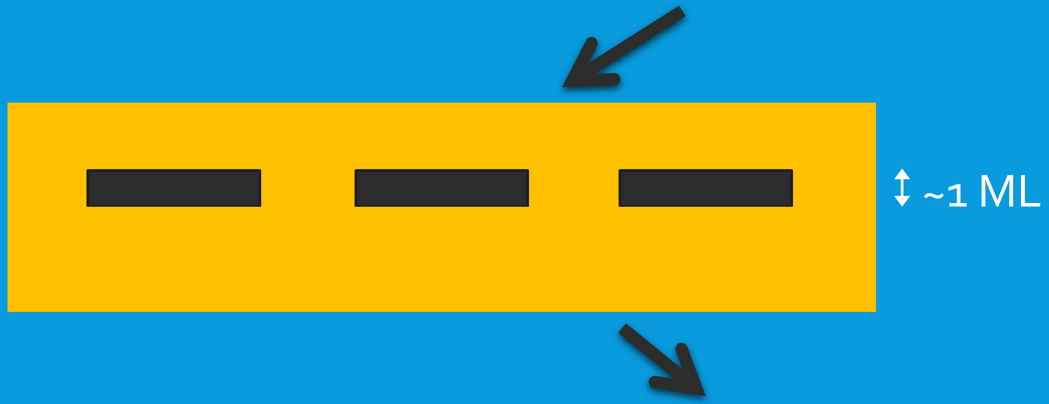
Low-dimensional nanostructures



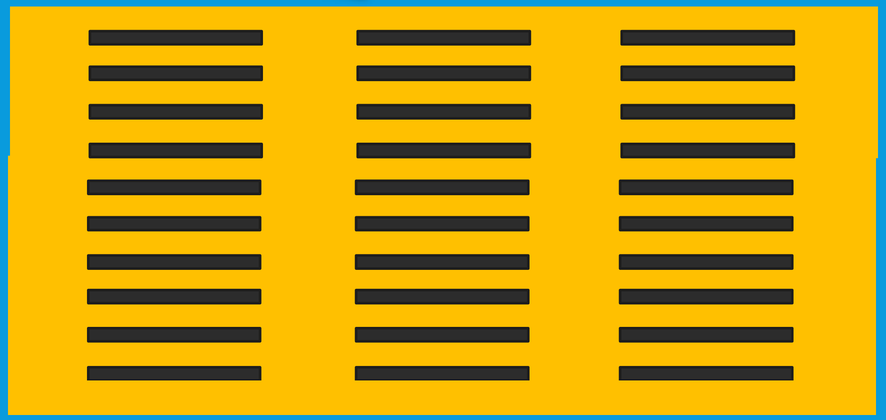
Our samples: “stacked sub-monolayer growth”

Deposit 0.5 MLs of InAs on GaAs

Cap with GaAs (1.5, 2.0 and 2.5 MLs in our samples)

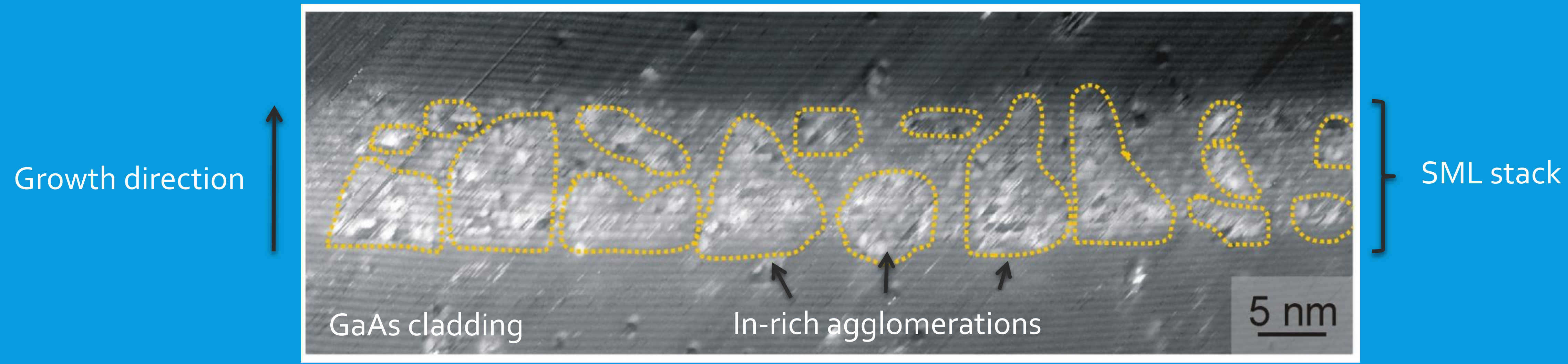


Repeat another 9 times



Actual structure[1]

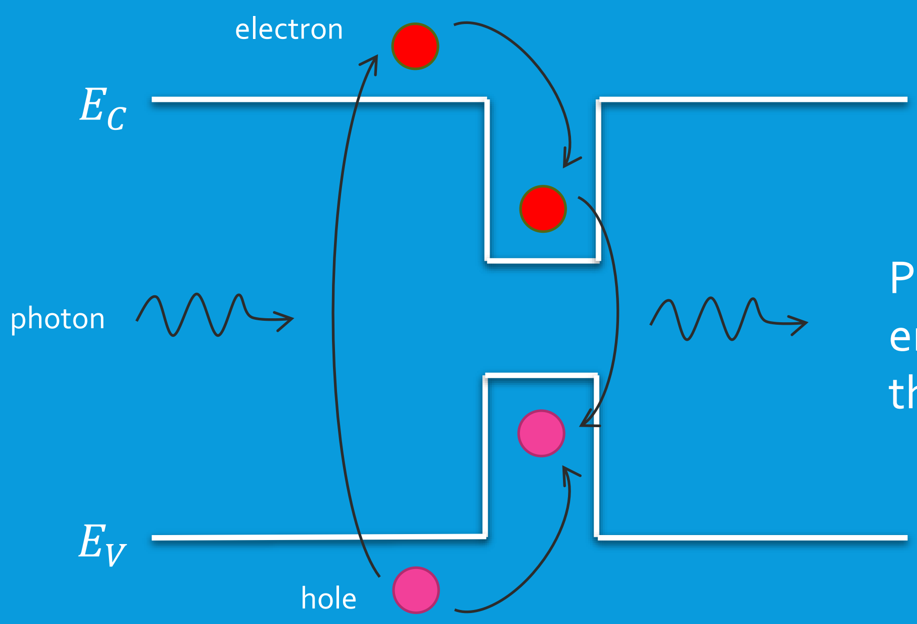
X-STM reveals QDs and quantum wells (QWs):



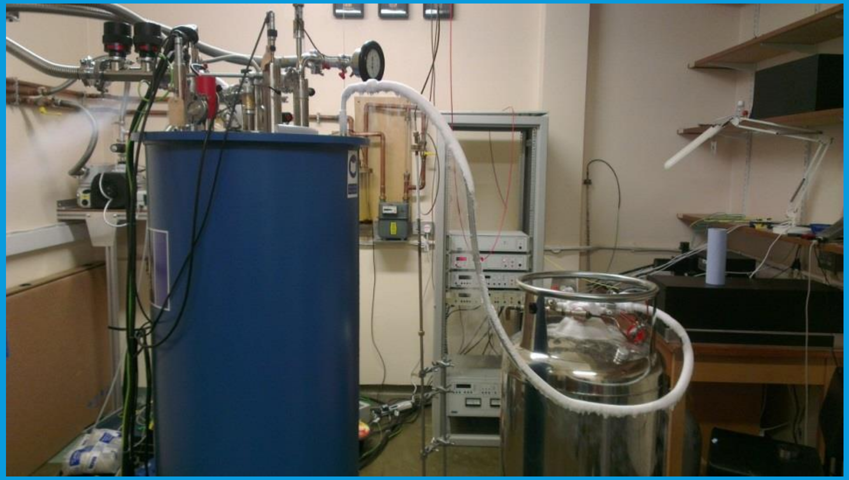
A zero- or two-dimensional system?

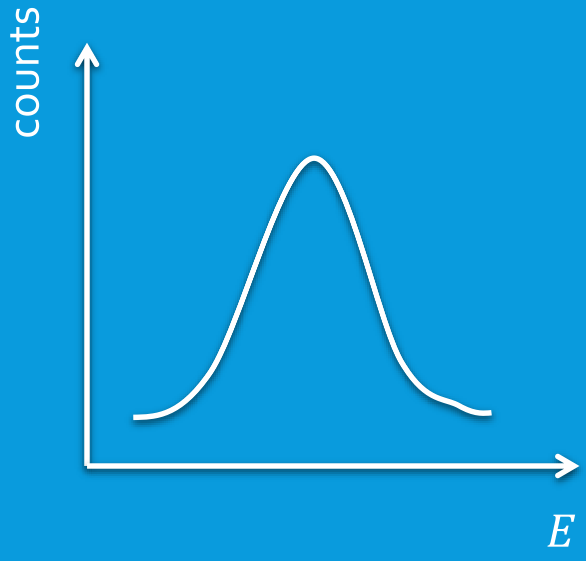
1 A. Lenz *et al*, J. Vac. Sci. Technol. B **29** 1071 (2011)

Photoluminescence (PL) in a magnetic field



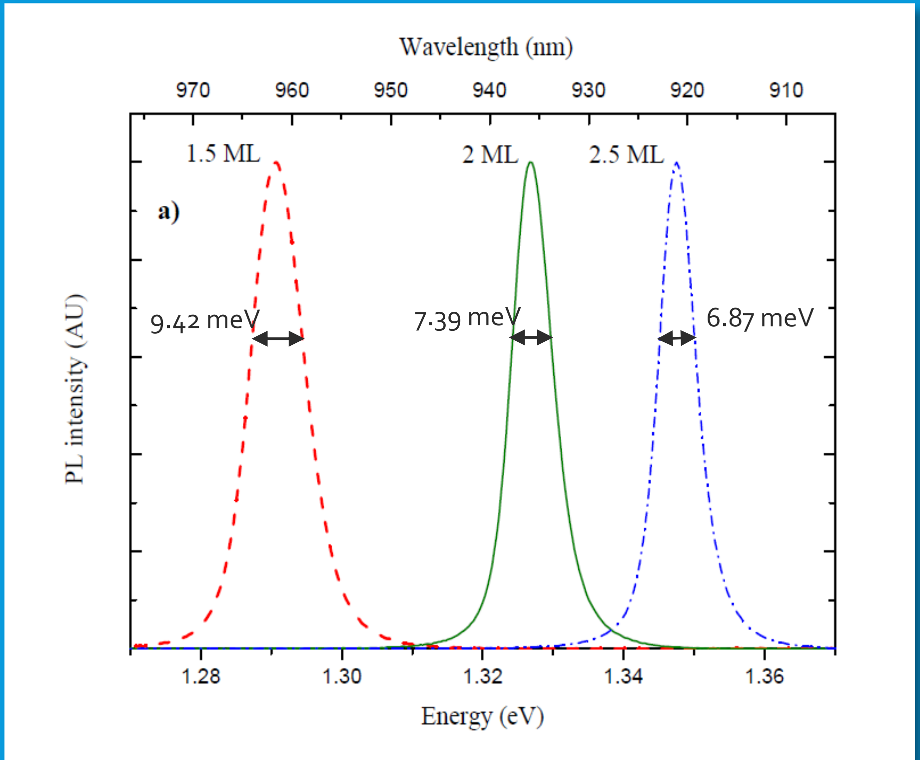
PL emission at a energy tuneable by the size of QD



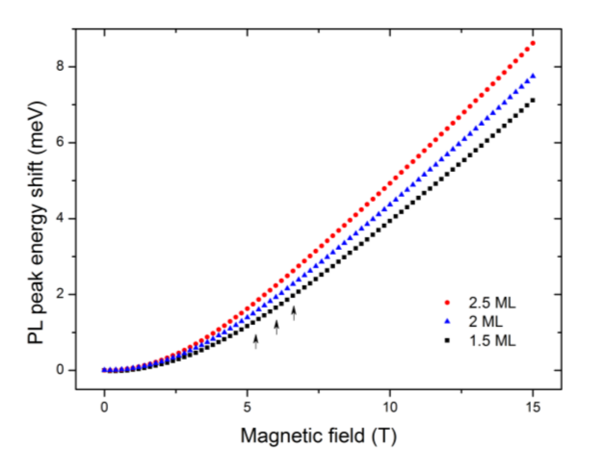


Gives us an idea of how charge carriers are confined

2D system?



Narrow line-widths (more akin to an InGaAs QW [1]).



Large Bohr radius (i.e. small confinement)

→ **2D system**

Spacer layer thickness (ML)	Stack height (nm)	Lateral geometry (B//z)	
		a_B (nm)	μ (m_o)
2.5	15.5	16.1	0.085
2.0	13.0	15.6	0.091
1.5	10.5	15.0	0.097

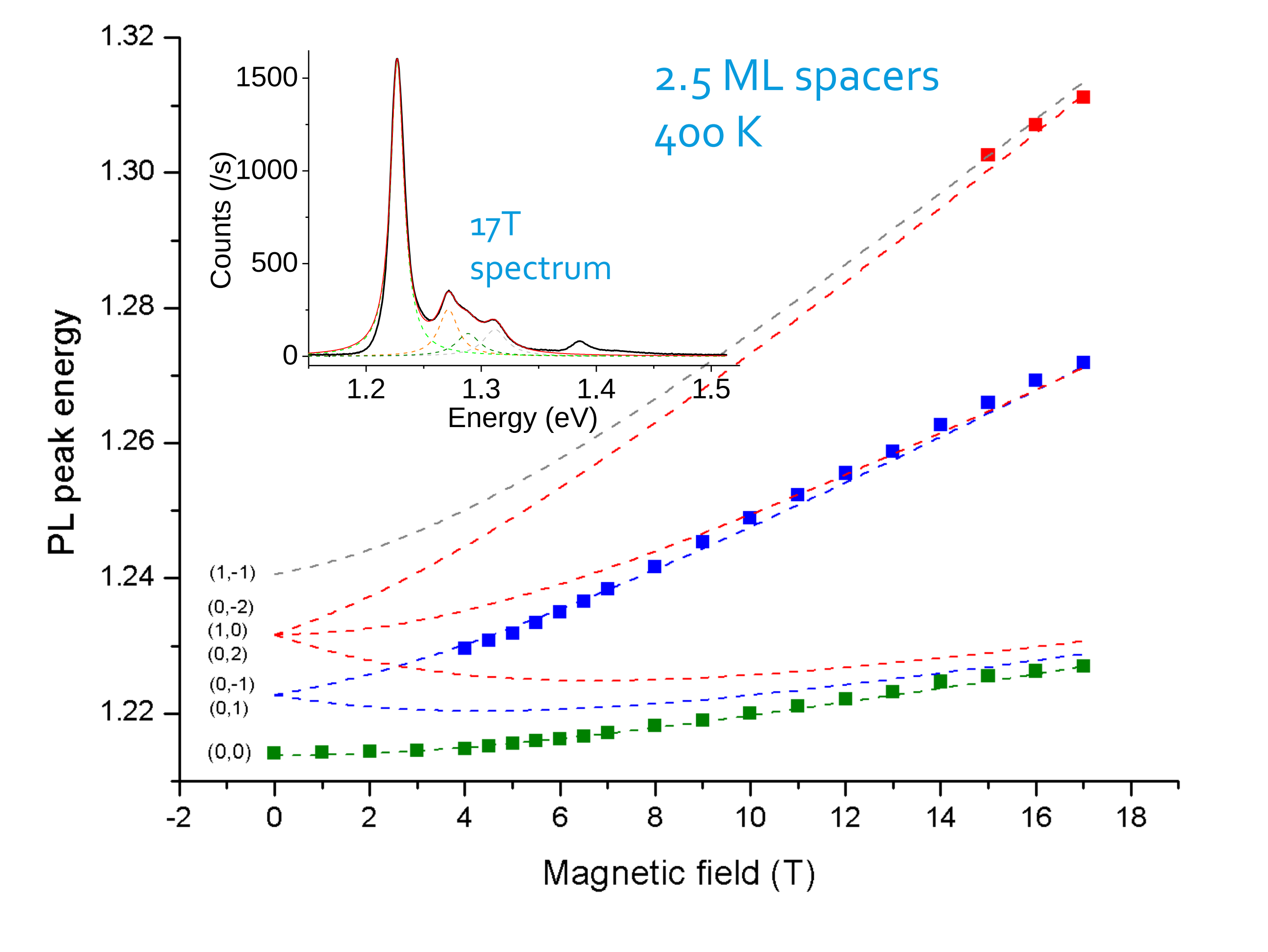
1 A. Lenz *et al*, J. Vac. Sci. Technol. B **29** 1071 (2011)

2 B. Bansal *et al*, Appl. Phys. Lett. 91, 251108 (2007)

0D system?

- Excited-state peaks visible at 400K.
- Fitted by **Fock-Darwin spectrum**.
- For our samples, **confinement energy ~ 9 meV**.

→ **0D system!**

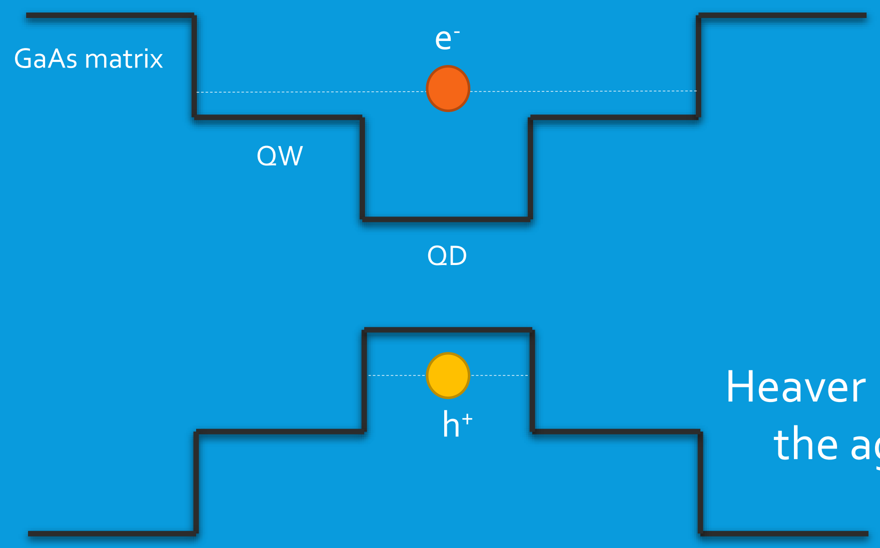


0D *and* 2D?

Different dimensionalities of confinement for electrons and holes.

→ Heterodimensional system

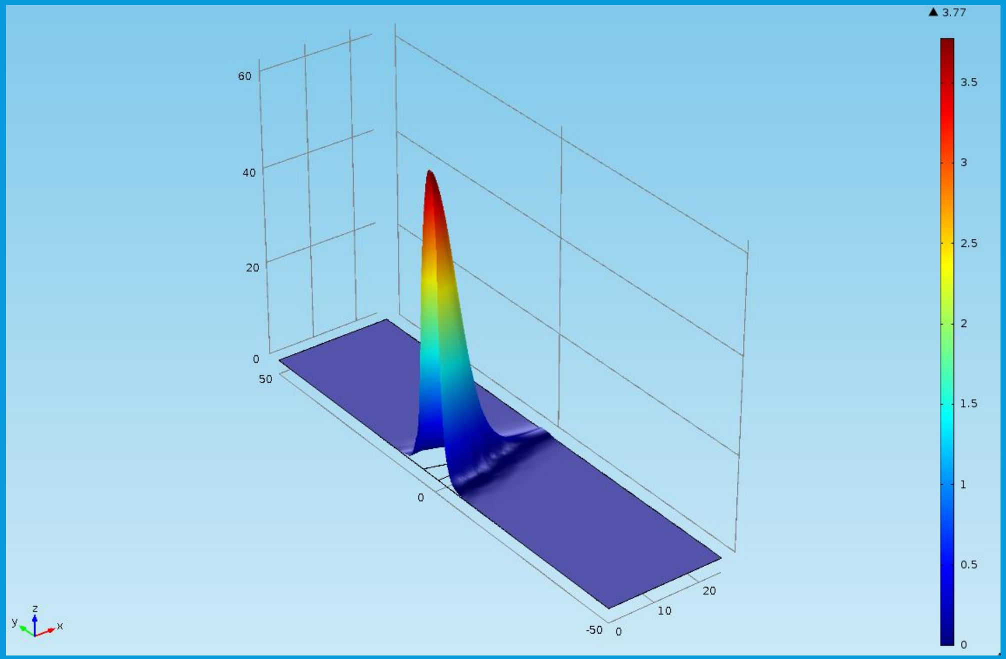
In-rich agglomerations too small to confine the light electrons, so they see an InGaAs QW.



Heaver holes confined in the agglomerations

Use of COMSOL

- Adapted the **Conical Quantum Dot** model for a QD in a QW.
- Solves the 1-band Schrodinger equation in the effective mass approximation.
- Gives us *energy levels* in the system, telling us whether they lie in the QD or QW.



wave function

energy level

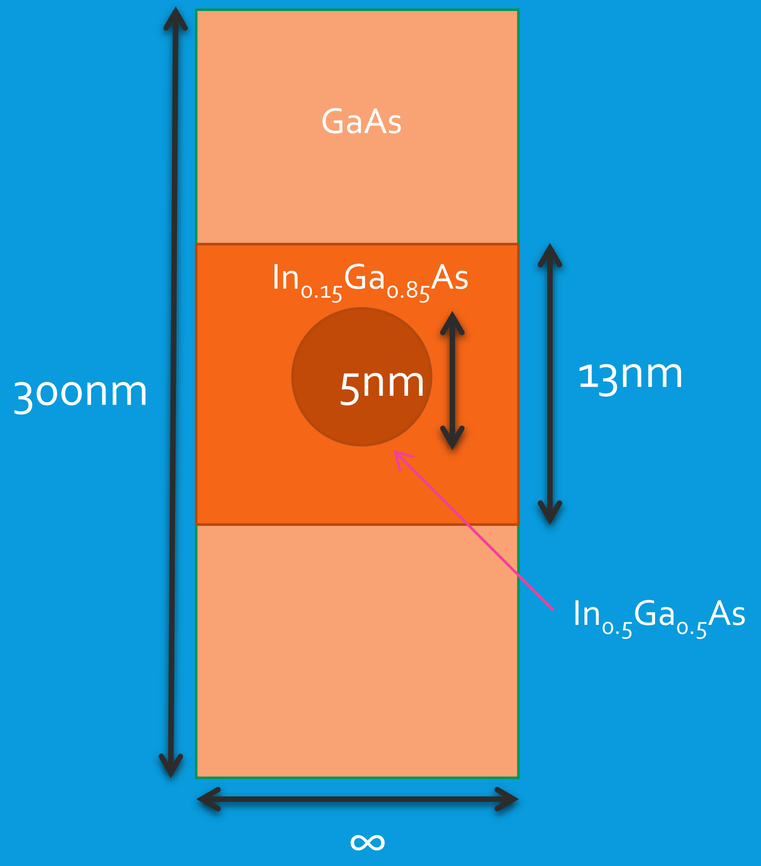
$$-\frac{\hbar^2}{8\pi^2}\left(\nabla\cdot\left(\frac{1}{m_e(r)}\nabla\Psi(r)\right)\right)+V(r)\Psi(\mathrm{r})=\mathrm{E}\Psi(r)$$

effective mass

potential well

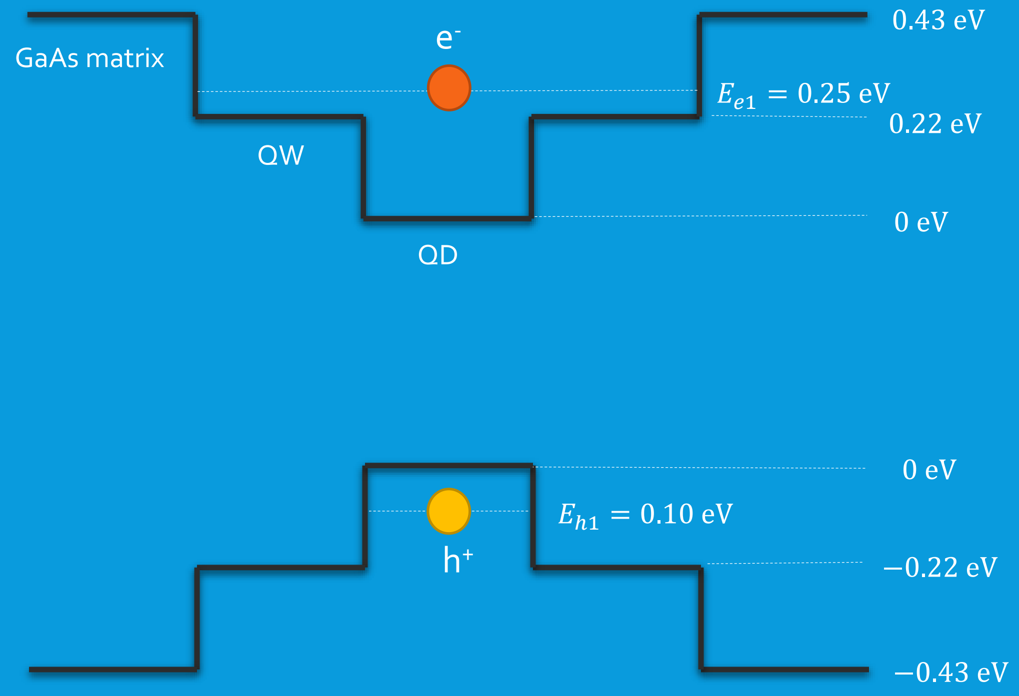
Effective mass modelling

- Simple model to solve 1-band Schrödinger equation in the effective mass approximation used to give energy eigenvalues for both electron and hole states.



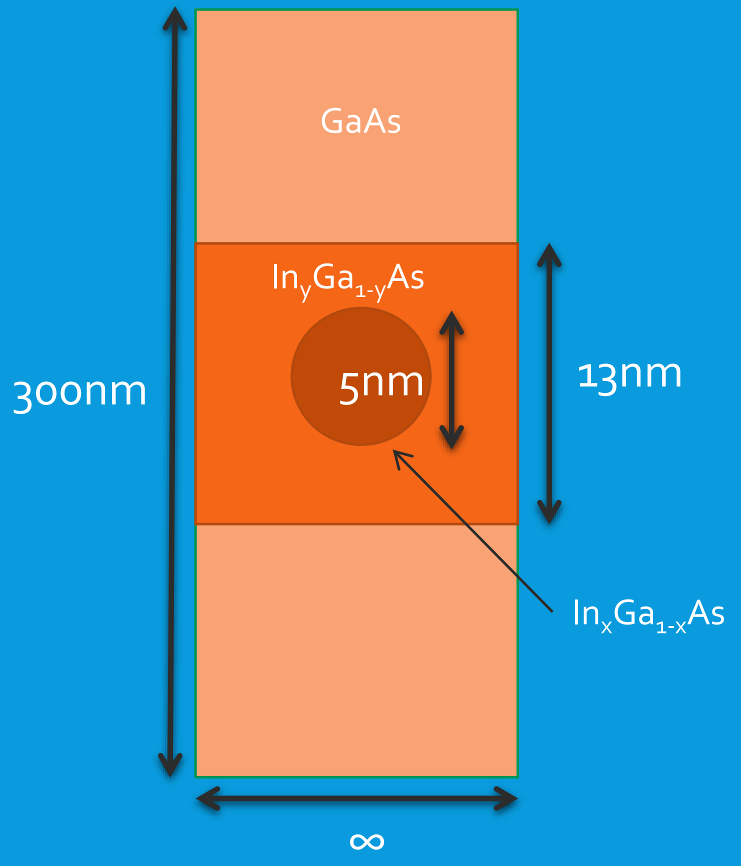
Electrons confined in QW:

Holes confined in QDs:

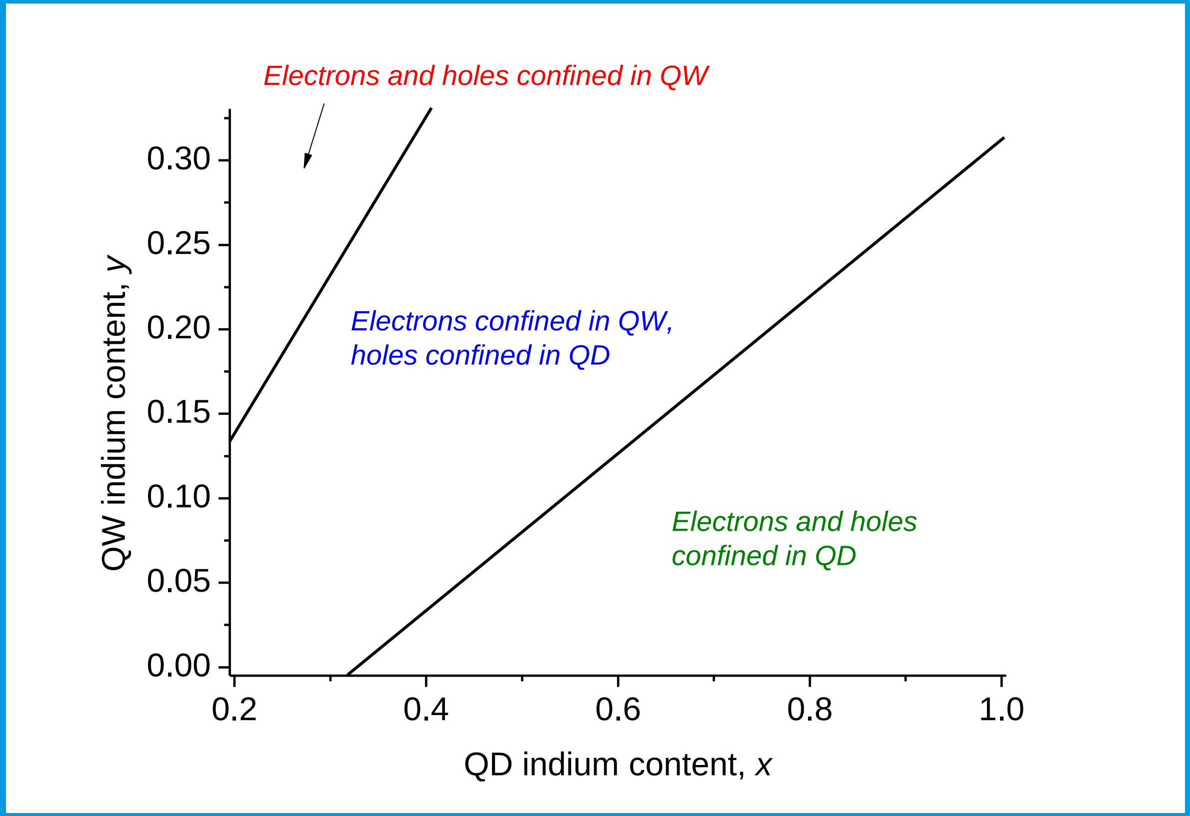


Effective mass modelling

Simple, single-band (effective mass) calculation supports this interpretation



Phase diagram of electron and hole confinement for differing In content



Summary

- Introduced the concept of **heterodimensional system**.
- Electrons confined in 2D, holes in 0D.
- Practical investigation backed up by use of COMSOL.

Paper submitted to PRL:

Zero-dimensional Holes in Two-dimensional Electrons

S. Harrison[1], M. P. Young[1], A. Schliwa[2], A. Strittmatter[2], A. Lenz[2], H. Eisele[2], U. W. Pohl[2], D. Bimberg[2], P. D. Hodgson[1], R. J. Young[1] and M. Hayne[1*]

For more details:

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