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Effect of In-Segregation on subbands in GaInAsN /GaAs quantum well for 1.3 and 1.55 micron emission wavelengths

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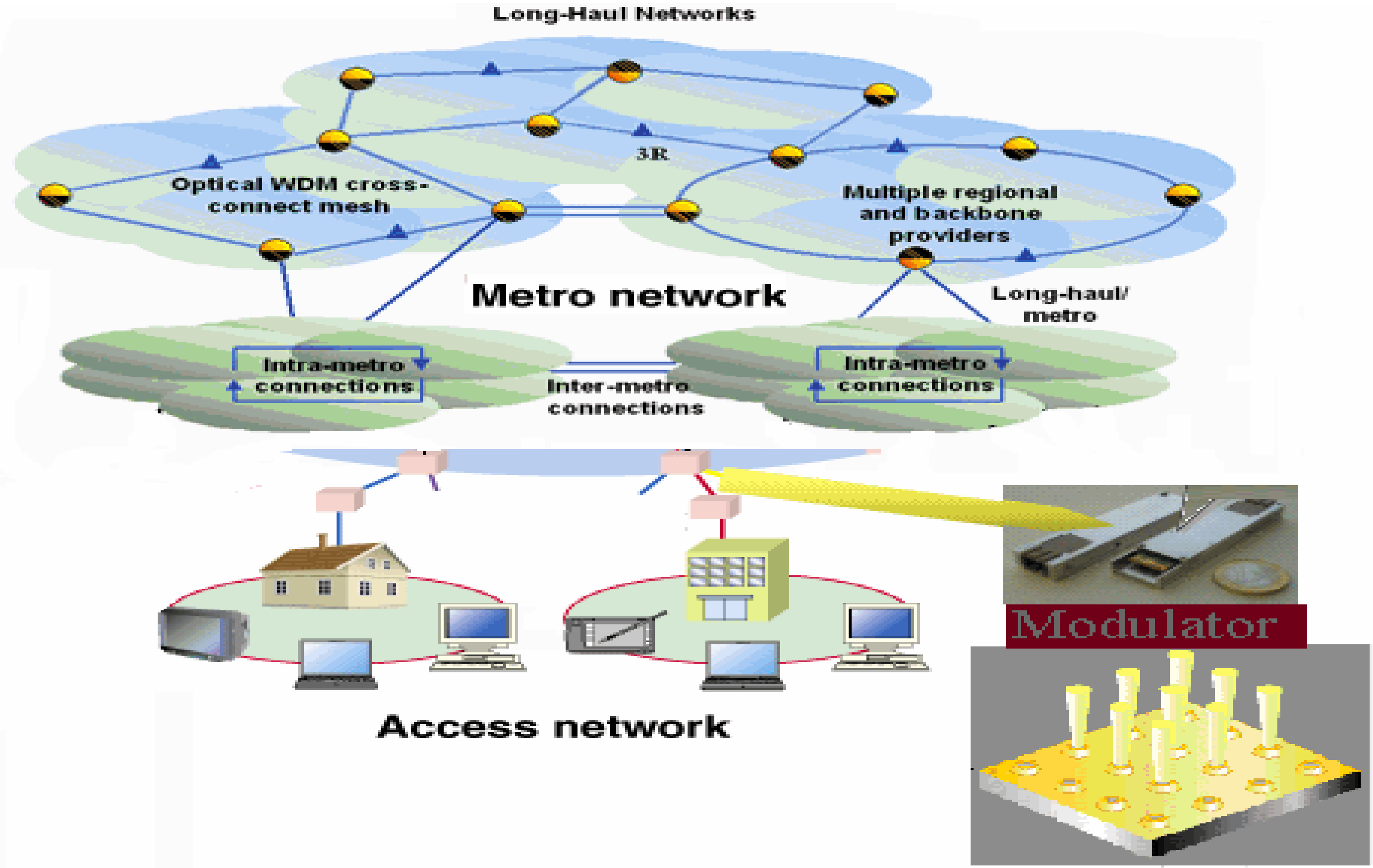
Outline

- Introduction
- Indium Segregation
- Segregation model
- Experimental Evidence
- Effect of strain on Bands
- Results
- Conclusion

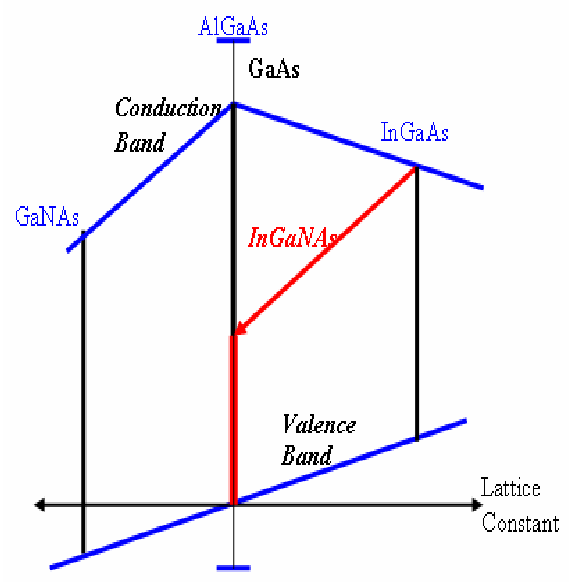
Introduction(1): Telecommunication requirement at 1.3 and 1.55 μm wavelength optical fiber.



10-Gbit/s directly modulated VCSEL laser

Introduction (2)

- Can be grown pseudomorphically on GaAs substrate.
  - Existing technology for 850 nm VCSEL
  - Good quality DBR's – $Al_xGa_{1-x}As/GaAs$
  - Cheaper substrate and Provides Oxide confinement possibility.
- Introduction of small amount of nitrogen reduces Band-gap energy to suitable for long-wavelength (1.26-1.6 μm).
- Type-1 Band lineup.
- Deep quantum well especially in Conduction Band providing stability to electron confinement. Improved temperature performance.
- Higher differential gain from increased electron mass (m_e^*).



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Surface Segregation

- In 1982 Chiang *et. al.* observed the surface of thick ternary AlGaAs to be almost pure GaAs.
- This was due to gallium atoms not being immediately incorporated into the crystal rather segregate to the surface.
- In 1989 Moison *et. al.* studied In segregation in InGaAs/GaAs QW and gave thermodynamic exchange model between indium and gallium atoms.
- A phenomenological model of segregation was given by Muraki *et. al.* in 1992, stating that impinging indium atoms are first incorporated into the crystal then a portion, R of the deposited indium atoms segregates to the floating layer.
- Our experimental results also show: Presence of nitrogen enhances the indium segregation in GaInAsN QW.

Segregation Model

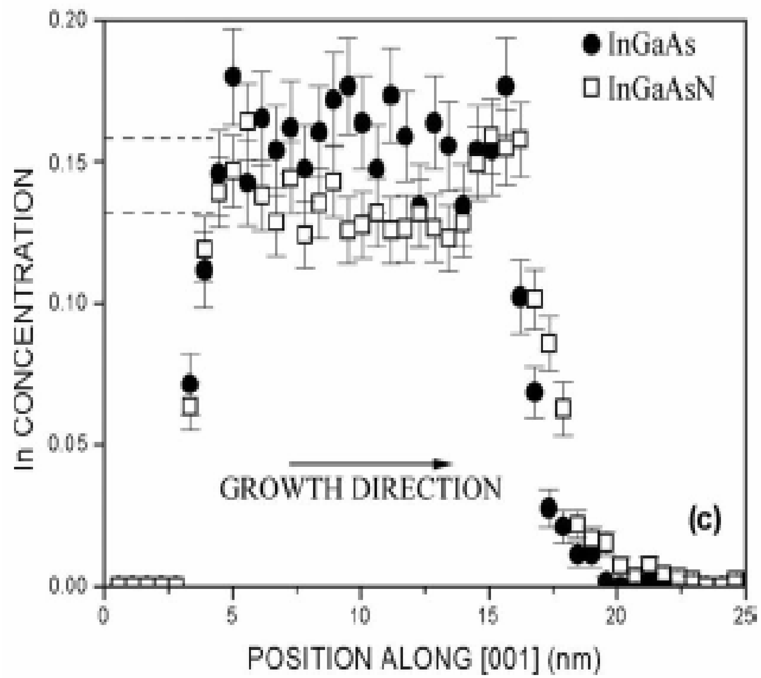
- Indium concentration profile for segregated QW can be deduced from Muraki's model. Presented as function of physical length using interpolation

$$x'(z) = \begin{cases} x_0'(1-R^{z/d}) & (0 \le z \le W; Well) \\ x_0'(1-R^{W/d})R^{(z-W)/d} & (W < z \le W+B; Barrier) \end{cases} \qquad (1.1)$$

- Where x'_0 is the nominal In concentration, d is monolayer thickness, W the *QW* thickness, z is distance in the growth direction and origin is beginning of QW and,
- *R*, is the segregation efficiency.

GaInAsN – Indium segregation

"it is surprising that little effort has been targeted to understand the effect of nitrogen incorporation on growth kinetics and indium content"

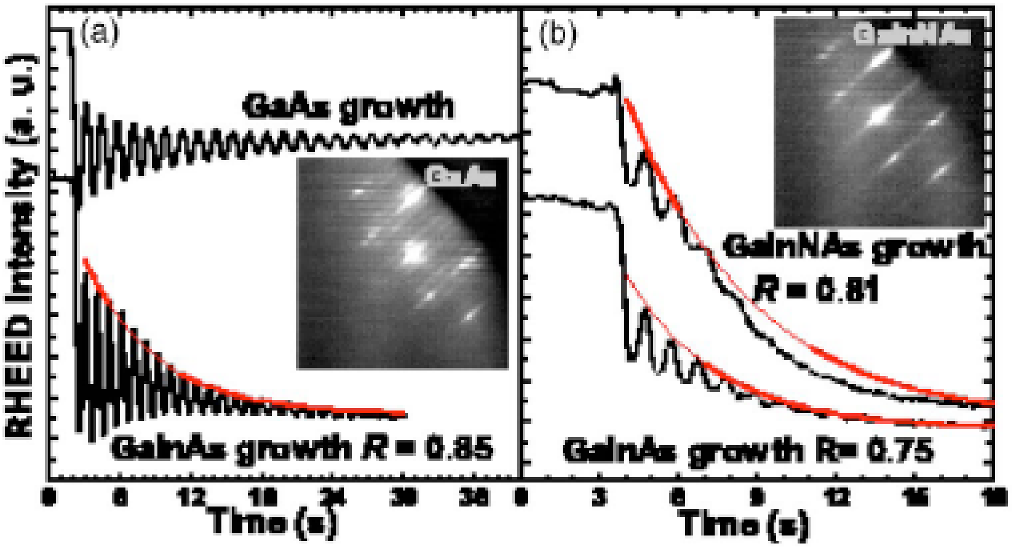


REF: Appl. Phys. Lett. 88, 141923 (2006)

Profile of the indium concentration x in the $In_xGa_{1-x}As$ and $Ga_{1-x}In_xAs_{1-y}N_y$ (12 nm) QWs; measured using XSTM.

GaInAsN – Indium segregation

- RHEED oscillations with their best fittings during the MBE growth of (a) GaAs and GaInAs at T_s=530 °C, and (b) GaInAs and GaInNAs at T_s=460 °C. The insets of (a) and (b) are the RHEED patterns taken from the growth of GaAs and GaInAsN, respectively.



RHEED Intensity

$$I = I_1 + I_0 \exp(-t/\tau)$$

Segregation efficiency

$$R = \exp(-1/\tau)$$

APL 89, 071905 (2006)

Hetrostructure 's Studied

- Single quantum well structures of GaInAsN /GaAs material were studied at 1.3 and 1.55µm operation wavelength.
- Diagram below shows the nominal composition and thickness of the QW.

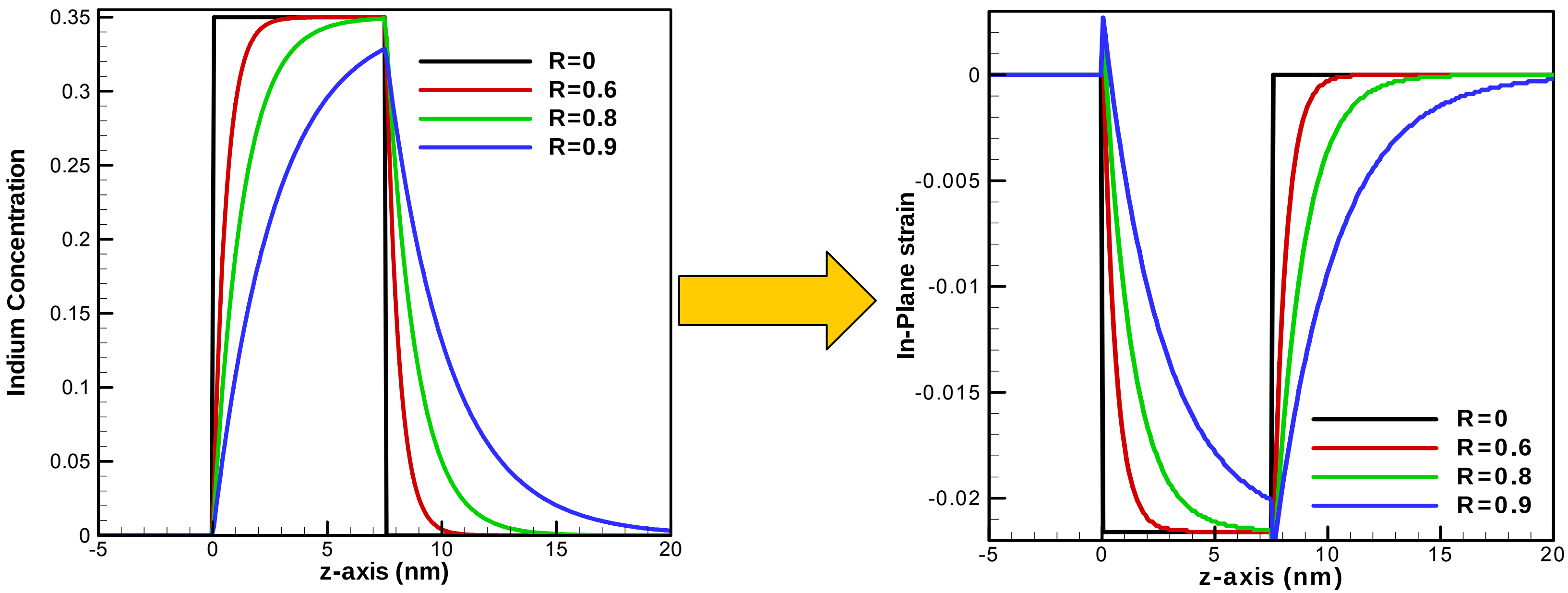
QW **at *1.3* µm**

GaAs barrier
7.5 nm $Ga_{0.65}In_{0.35}As_{0.985}N_{0.015}$
GaAs barrier/buffer

QW **at *1.55* µm**

GaAs barrier
7.5 nm $Ga_{0.61}In_{0.39}As_{0.97}N_{0.03}$
GaAs barrier/buffer

Indium and strain distribution profiles



- Here, left figure shows the Indium concentration profile in and around QW for various segregation efficiencies; and
- Right figure shows in-plane strain profile resulting from indium segregation.

Segregation- Effect on Bands

- Chosen GaInAsN QW is compressively strained. The resulting hydrostatic strain shifts the band edge of the conduction band and valence band by,

$$\Delta E_r(x',y') = 2a_r(x',y')\left(1-\frac{c_{12}(x',y')}{c_{11}(x',y')}\right)\varepsilon(x',y')$$

- The shear strain breaks the degeneracy of the heavy hole and light hole in the valence band, pushing the heavy hole up.

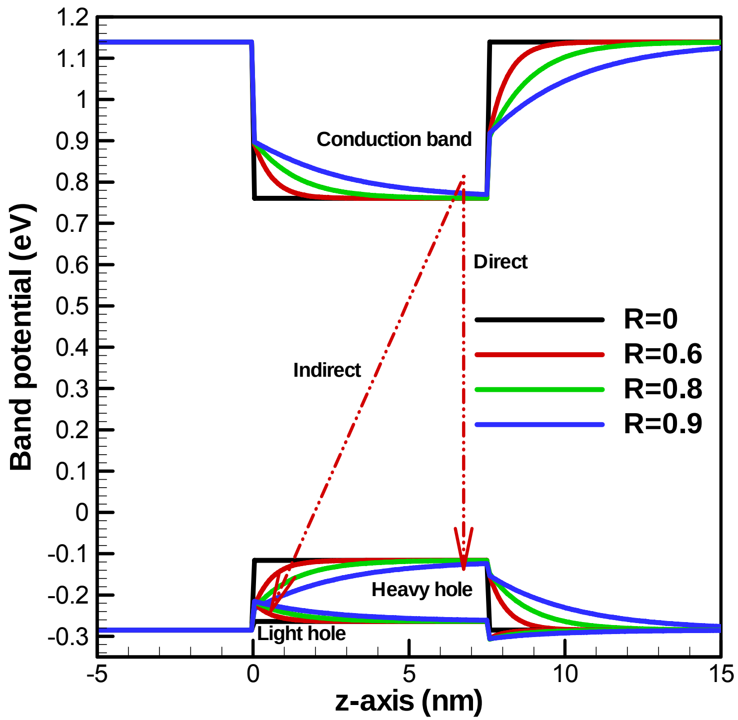
$$\Delta S(x',y') = -b(x',y')\left(1+2\frac{c_{12}(x',y')}{c_{11}(x',y')}\right)\varepsilon(x',y')$$

- Conduction band and valence band are decoupled in GaAs based materials. The energy states and wave function of electron, heavy hole and light hole at Γ_6 can be calculated using Duke-Daniel model by solving the 1-D wave equation in Schrödinger equation like form.

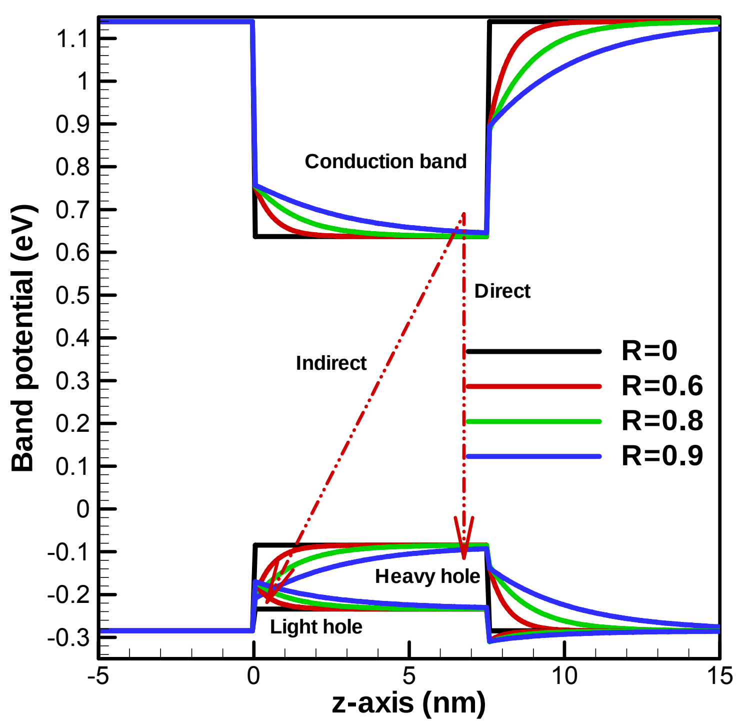
$$-\frac{\hbar^2}{2}\frac{\partial}{\partial z}\left[\frac{1}{m_r^*(z)}\frac{\partial \Psi_{rl}(z)}{\partial z}\right] + U_r(z).\Psi_{rl}(z) = E_{rl}\Psi_{rl}(z)$$

Band Structure for QW's

We show a Band structure for the QW's and the space-indirect transition between light holes localized in N-rich region and electrons localized in indium rich region of the quantum well.

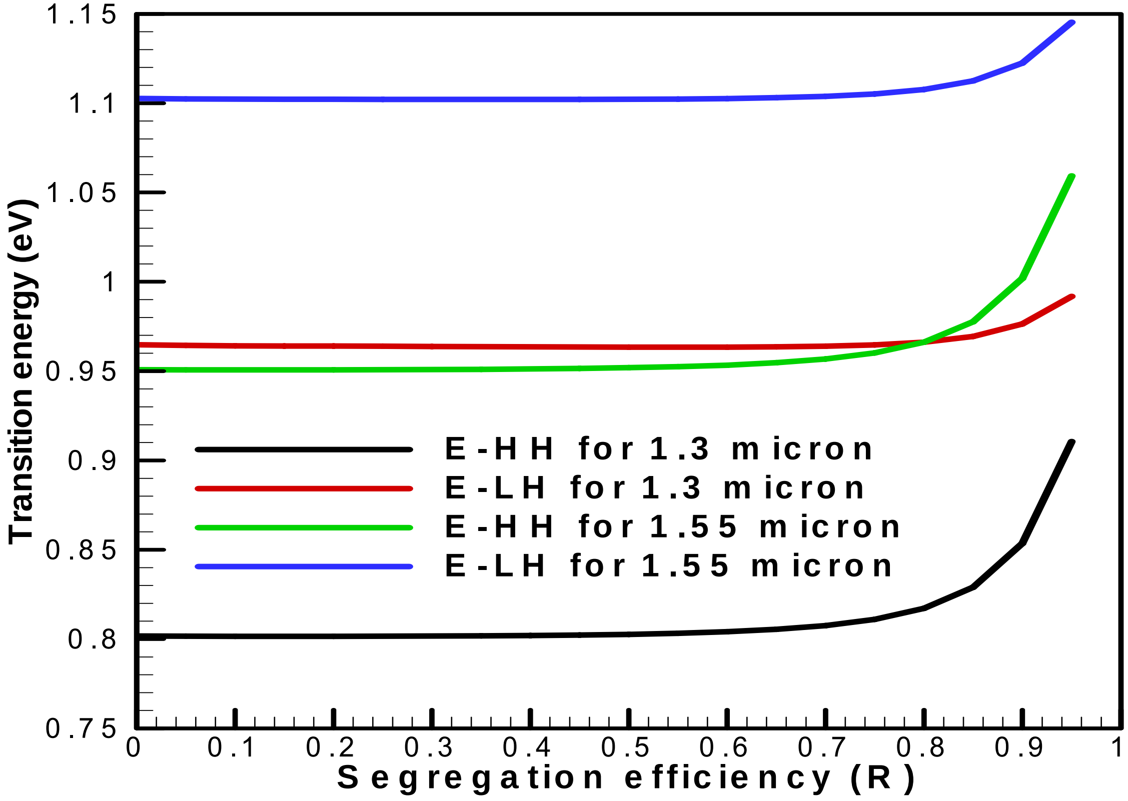


QW at *1.3* μm



QW at *1.55* μm

Effect on Transition energy



Conclusion

- Indium segregation profile was modelled using interpolated Muraki's model.
- Resulting strain profile and effect on Band structure showed separate confinements for light hole and heavy holes, showing space indirect transition between light hole and electron.
- Effect of segregation mainly comes from strain instead of concentration.
- Our results suggest that only the segregations with $R \geq 0.7$ can be observed experimentally by PL. Segregations with $R < 0.7$ can not be resolved by PL, however it does mean their absence in the QWs.

Thank you

Any Question ?