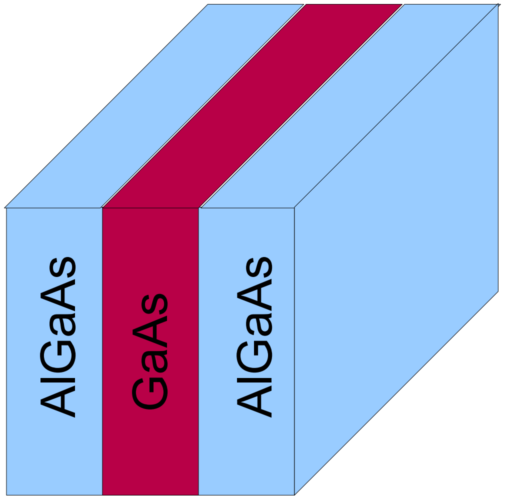
Two Dimensional Quantum Wells

- Quasi-2D properties
- Growth technique
- Basic spectroscopy (eg. Absorption spectroscopy)
- Conclusion

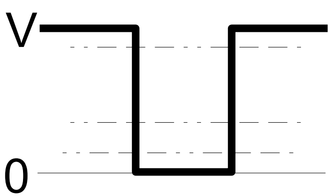
Quantization

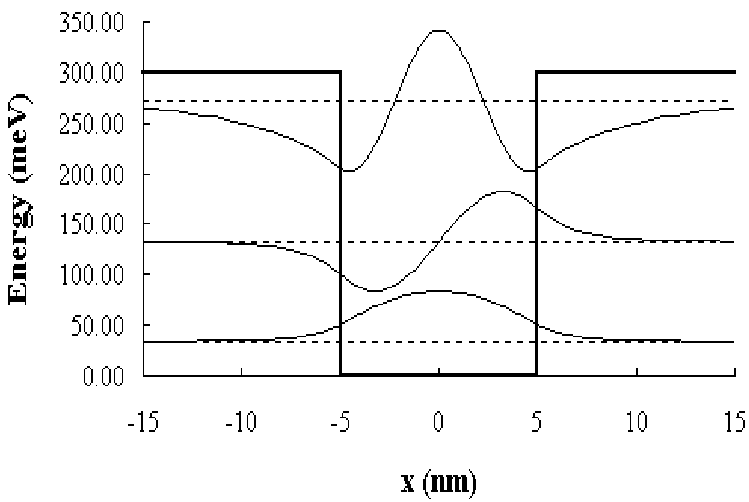


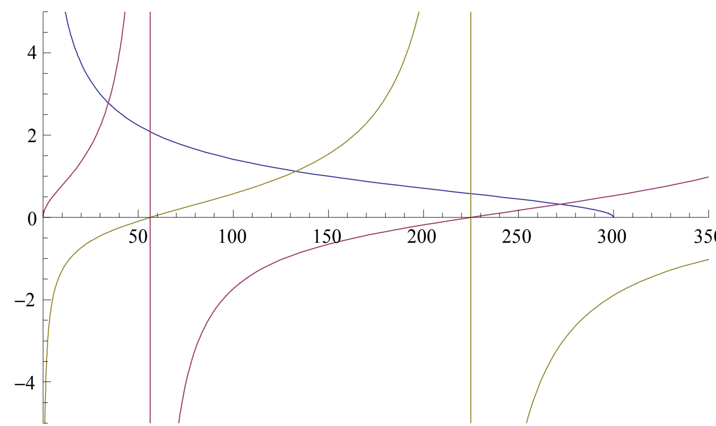
$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + V(x)\psi = E\psi$$

$$\frac{\sqrt{2m(V-E)}}{\hbar} = \begin{cases} k\tan(ka) \\ -k\cot(ka) \end{cases}$$

e.g. GaAs / AlGaAs Conduction band

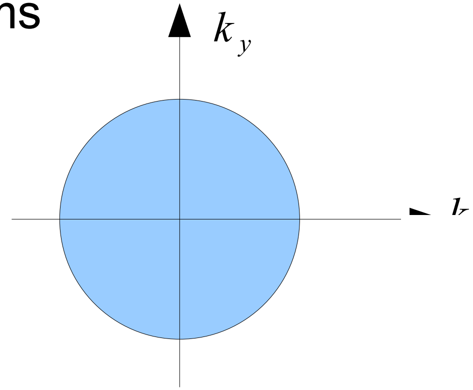




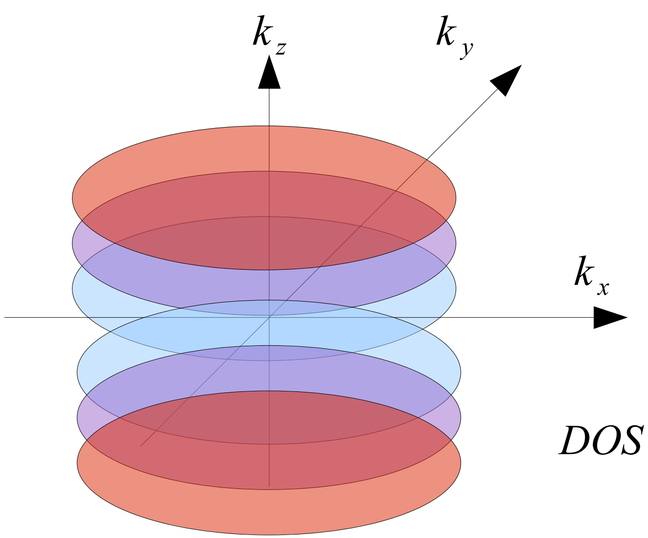


Ideal 2D systems

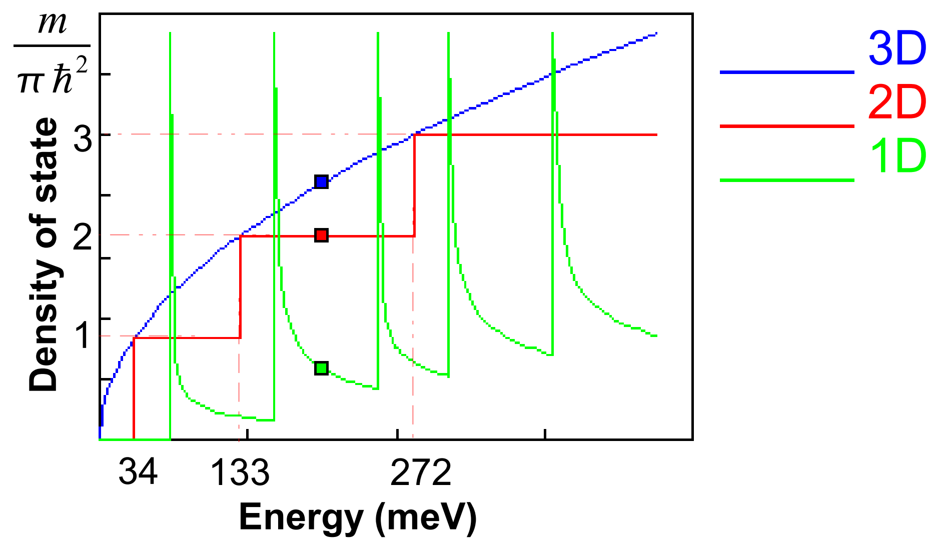
$$DOS = \frac{m}{\pi \hbar^2}$$



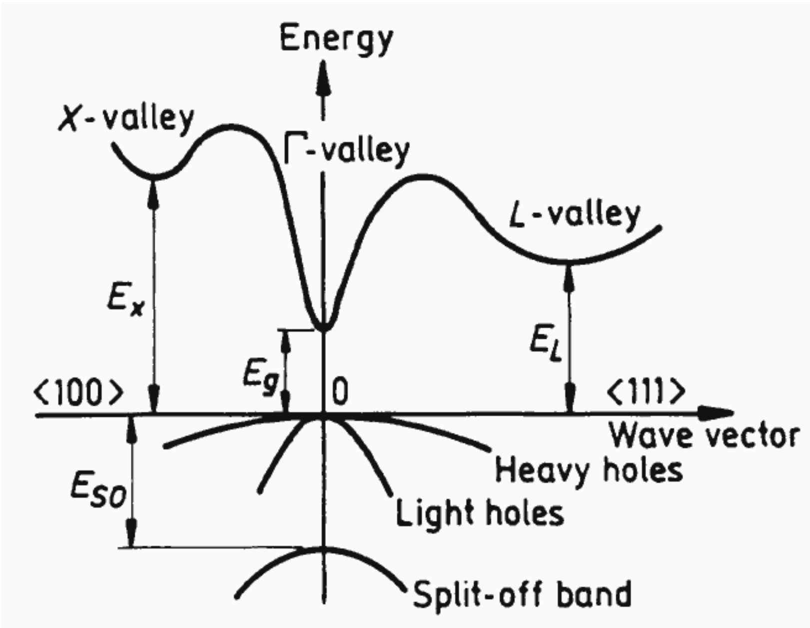
QW is a quasi-2D system.



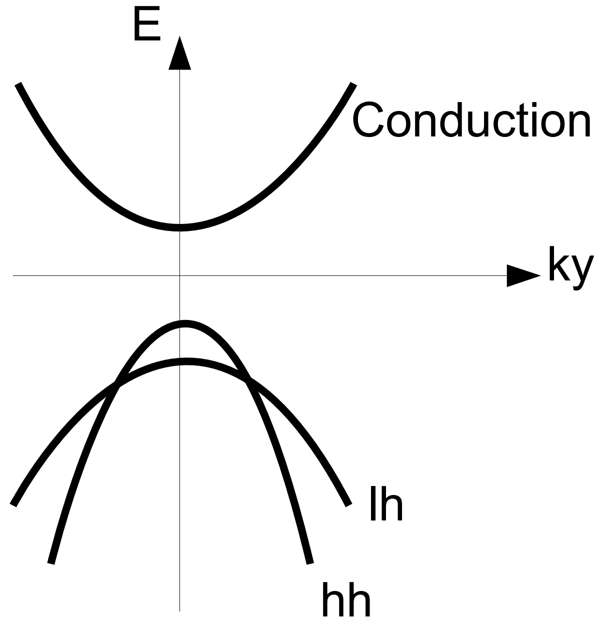
$$DOS = n \frac{m}{\pi \hbar^2}$$



Heavy hole and Light hole



Band structure in Bulk GaAs



$m_e = 0.064\, m_0,\ m_{lh} = 0.08\, m_0,\ m_{hh} = 0.5\, m_0$

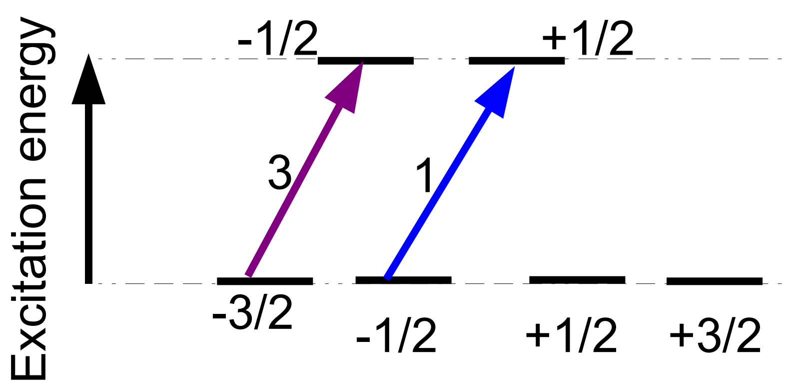
Luttinger Hamiltonian, $H = \frac{\hbar^2}{2m_0}((\gamma_1 + \frac{5}{2}\gamma_2)k^2 - 2\gamma_2(k_x^2 J_x^2 + k_y^2 J_y^2 + k_z^2 J_z^2) - 4\gamma_3\{k_x, k_y\}\{J_x, J_y + ...\})$

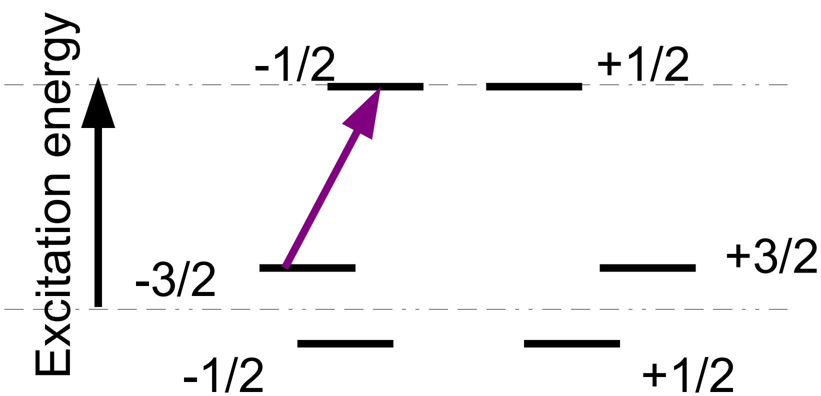
$For\ GaAs,\ \gamma_1 = 6.84,\ \gamma_2 = 2.1,\ \gamma_3 = 2.9$ "The Physics of Low_Dimensional Semiconductor" John H. Davies

$$m_{hh} = \frac{m_0}{\gamma_1 - 2\gamma_2},\ m_{lh} = \frac{m_0}{\gamma_1 + 2\gamma_2}\ along\ z\,(growth)\ direction$$

$$m_{hh} = \frac{m_0}{\gamma_1 + \gamma_2},\ m_{lh} = \frac{m_0}{\gamma_1 - \gamma_2}\ along\ xy-direction$$

Selective spin excitation in Quantum Well

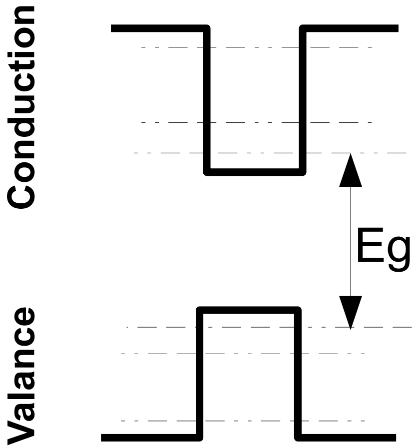


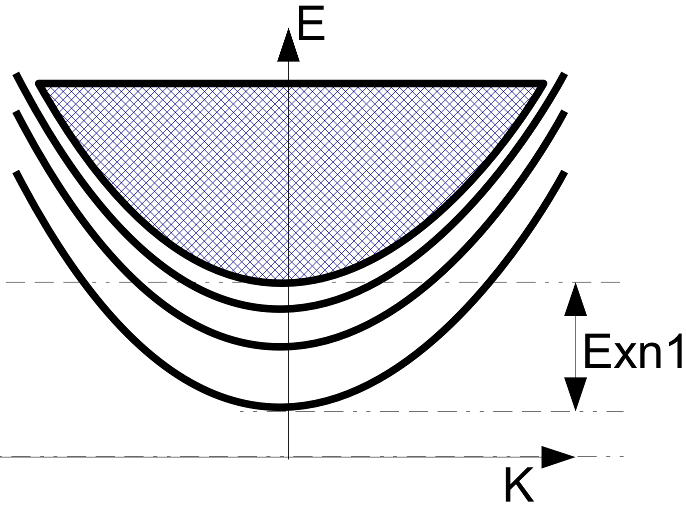


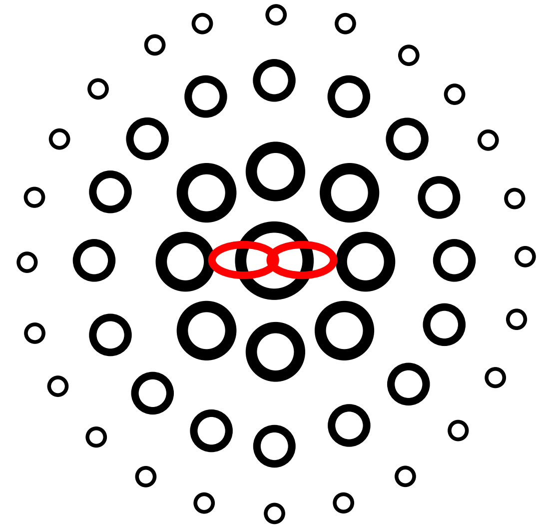
Excited to 3 (-1/2) + 1(+1/2)
Maximum polarizability = (3-1)/(3+1) = 50%

Excite only to -1/2 state
Polarization = 100%

Exciton







$$E_{xn}^{3D} = E_g - \frac{R_y}{n^2}, \text{ where } R_y = \frac{m_{eff}}{2}\left(\frac{e^2}{4\pi\epsilon_0\epsilon_b\hbar}\right)^2$$

3D_GaAs , binding energy ~ 4.8meV

$$E_{xn}^{2D} = E_g - \frac{R_y}{(n-1/2)^2}$$

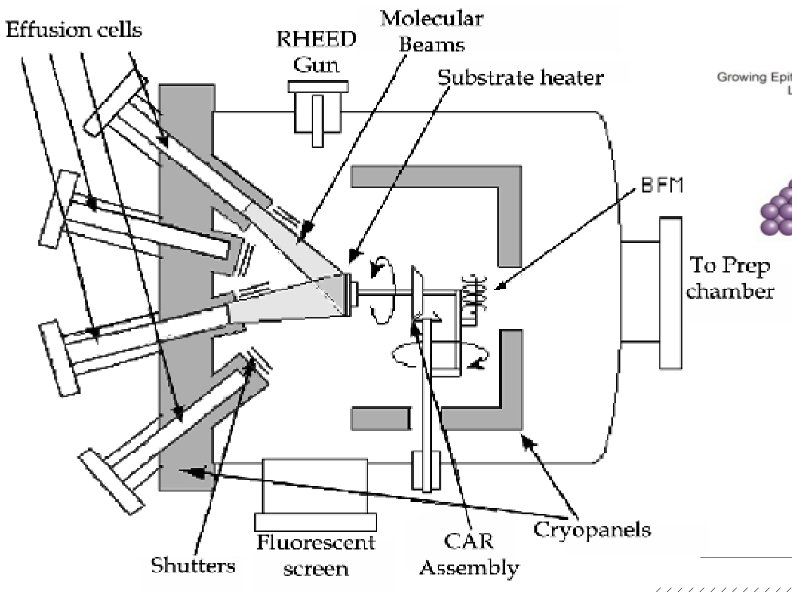
In 2D, exciton binding energy increases 4 times.

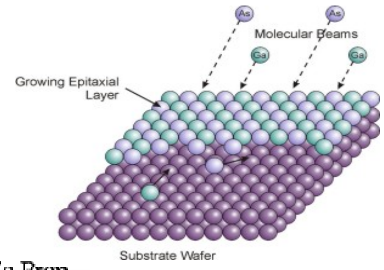
2D_GaAs, binding energy ~ 19.2meV

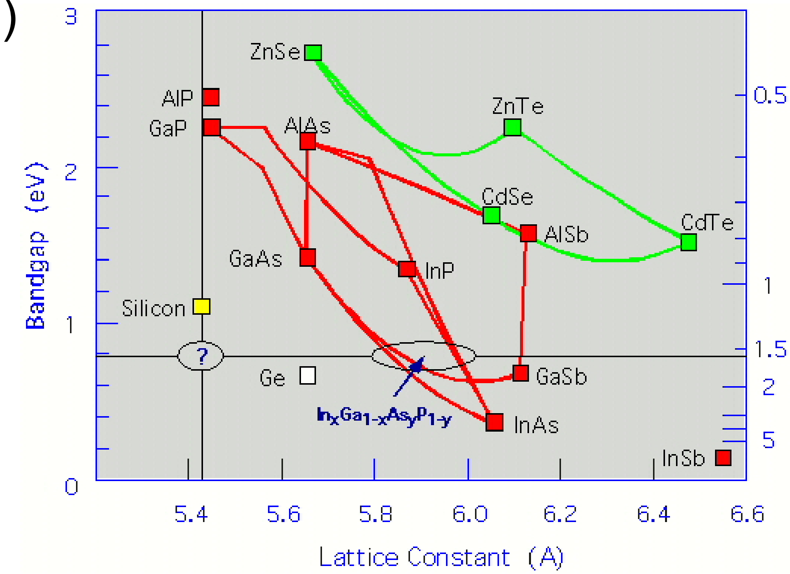
room temperature ~ 25 meV

MOCVD (Metal-organic chemical vapour deposition)

MBE (Molecular-beam epitaxy)





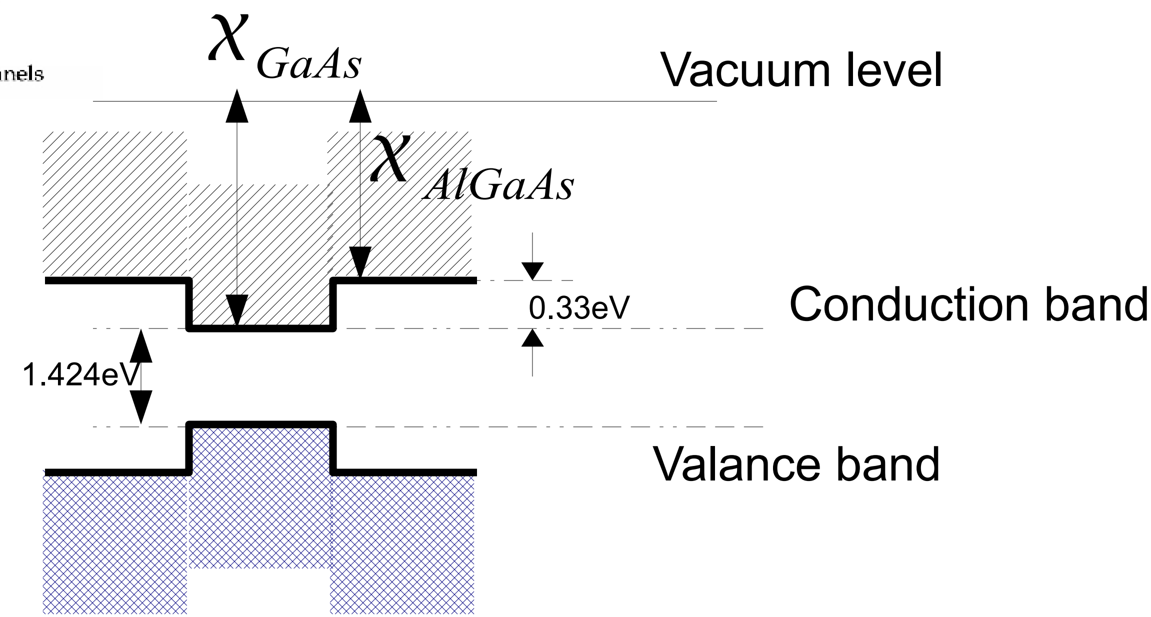


Anderson's rule

Vacuum level must match.

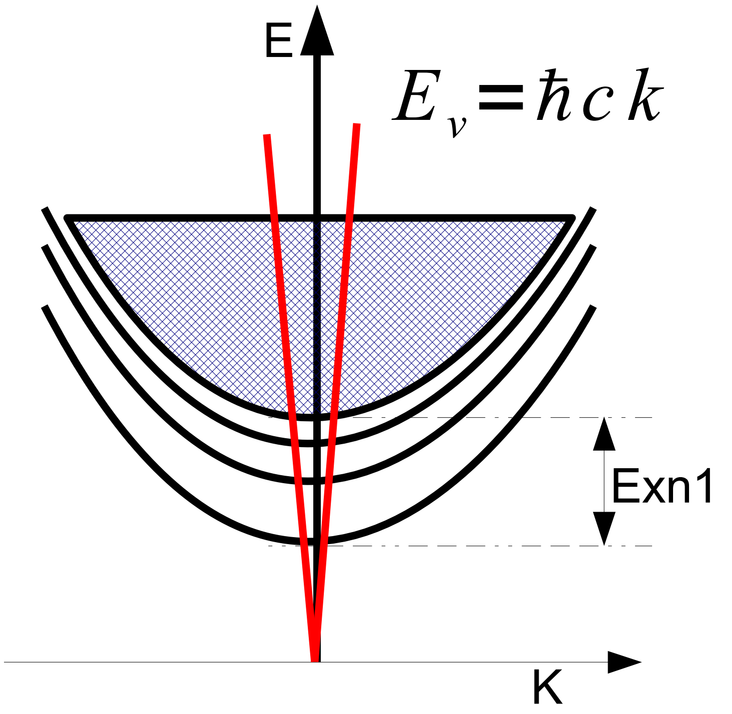
$$\chi_{GaAs} = 4.07\text{eV}$$

$$\chi_{Al_{0.3}Ga_{0.7}As} = 3.74\text{eV}$$



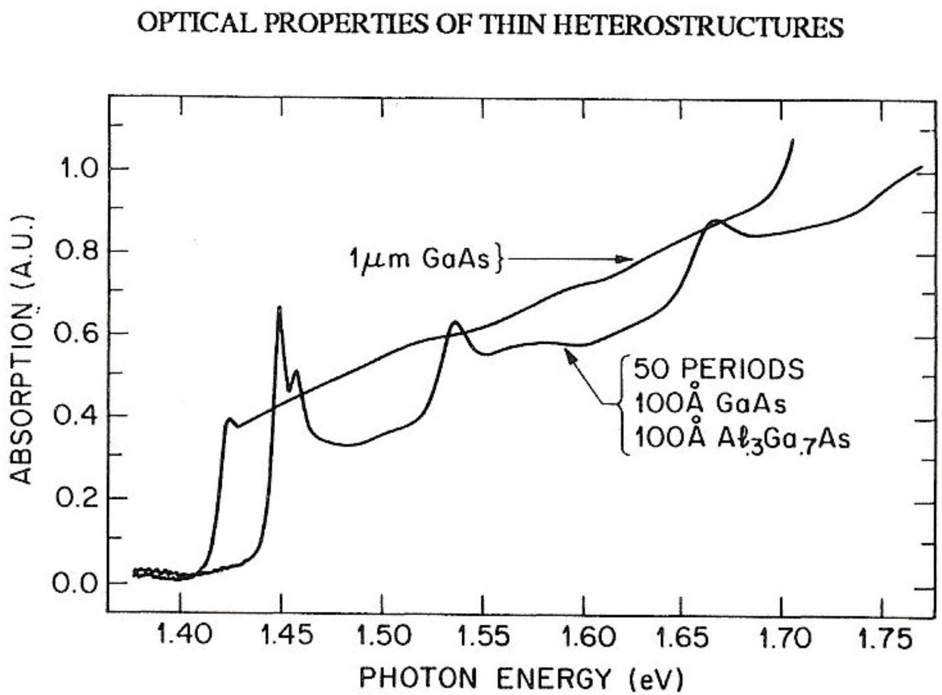
Spectroscopy (Light-matter interaction)

- Absorption spectroscopy
- Photo-luminescent spectroscopy
- Raman spectroscopy
-
-



eg. wavelength=800nm excitation at GaAs (me=0.06 m0)
parabolic approximation ---> ΔE=0.6 meV

Absorption spectroscopy



GaAs / AlGaAs QW absorption measurement

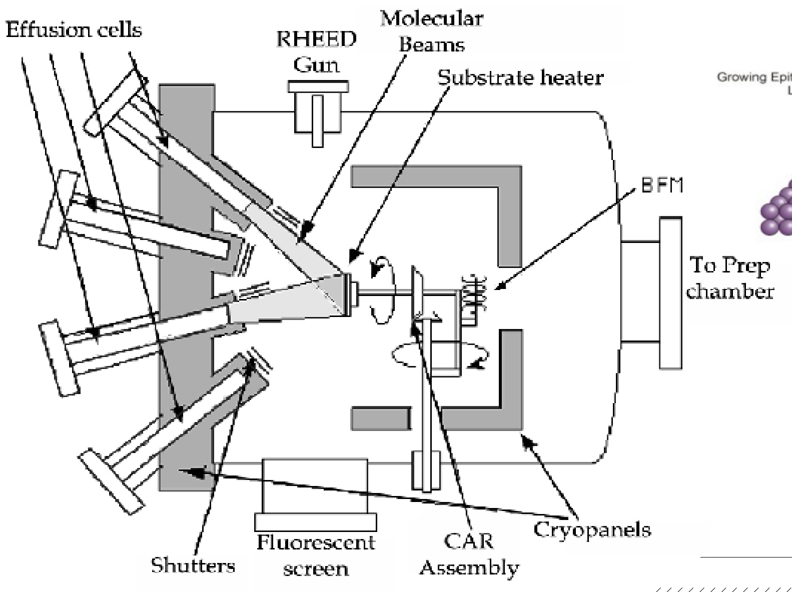
Application and outlook

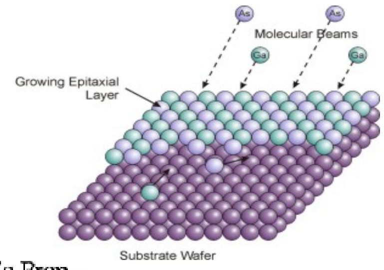
- Quantum well laser
- Electron spin control
- Room temperature exciton applications
- Lattice mismatch problem and strain

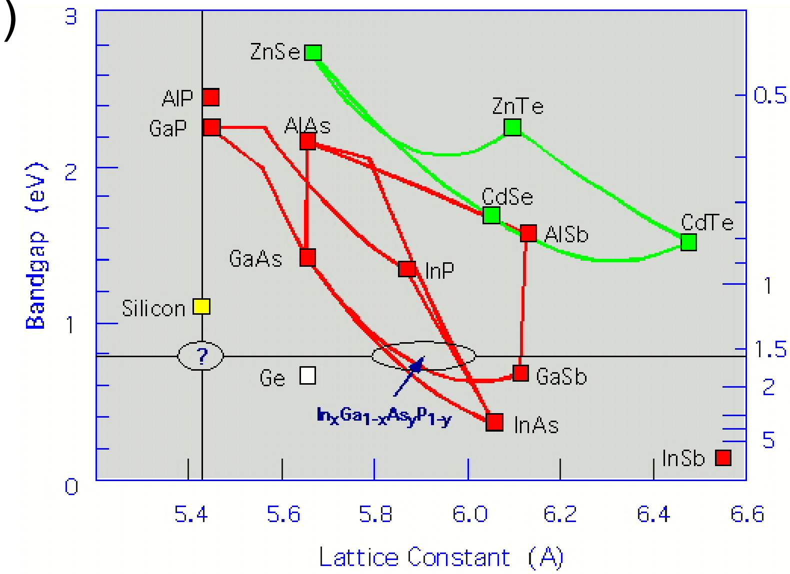
Thank you

MOCVD (Metal-organic chemical vapour deposition)

MBE (Molecular-beam epitaxy)







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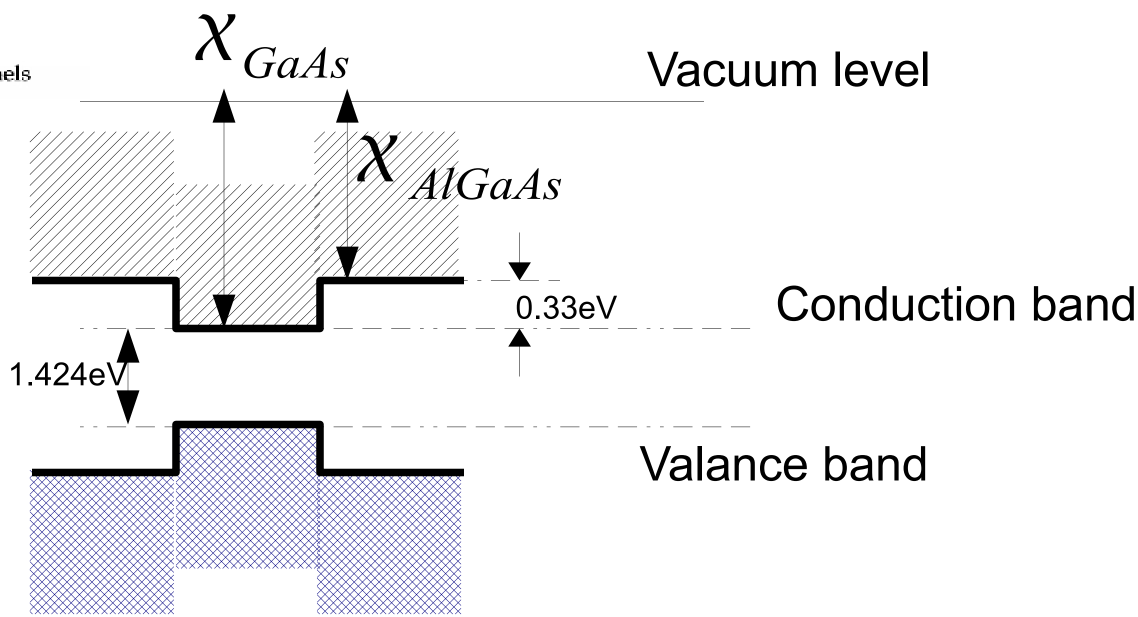
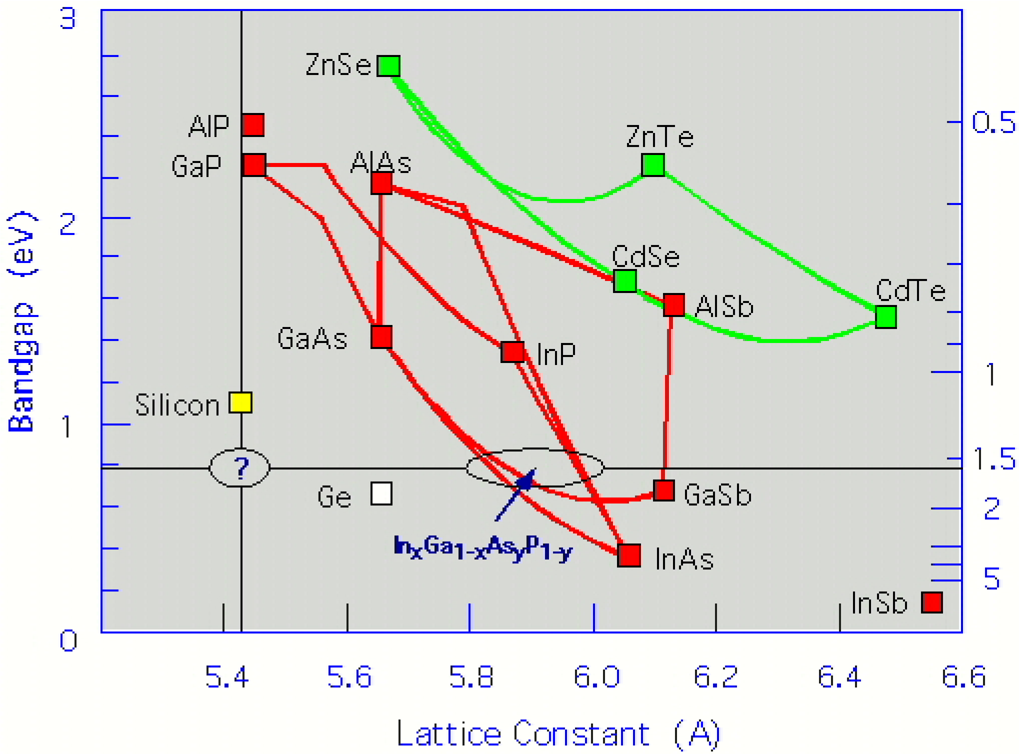




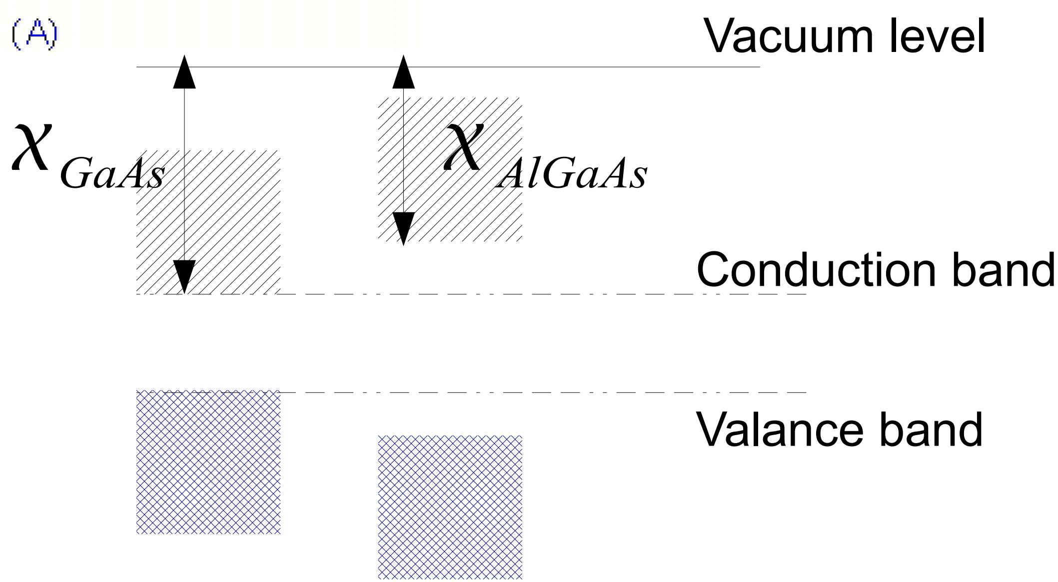
Lattice constant must match to avoid strain in the structure.

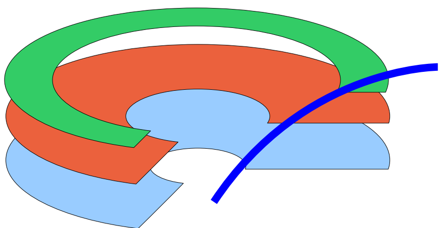
Anderson's rule

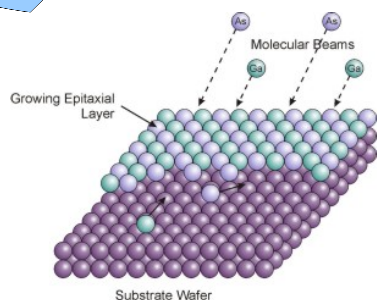
Vacuum level must match.

$$\chi_{GaAs} = 4.07\text{eV}$$

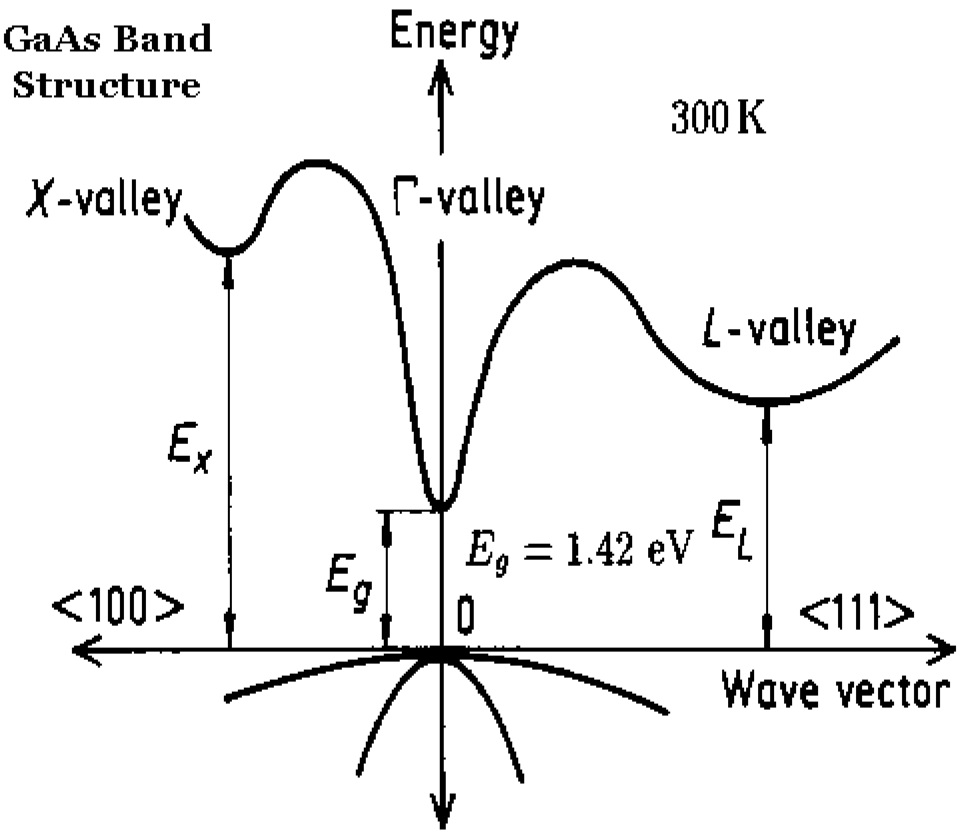
$$\chi_{Al_{0.3}Ga_{0.7}As} = 3.74\text{eV}$$

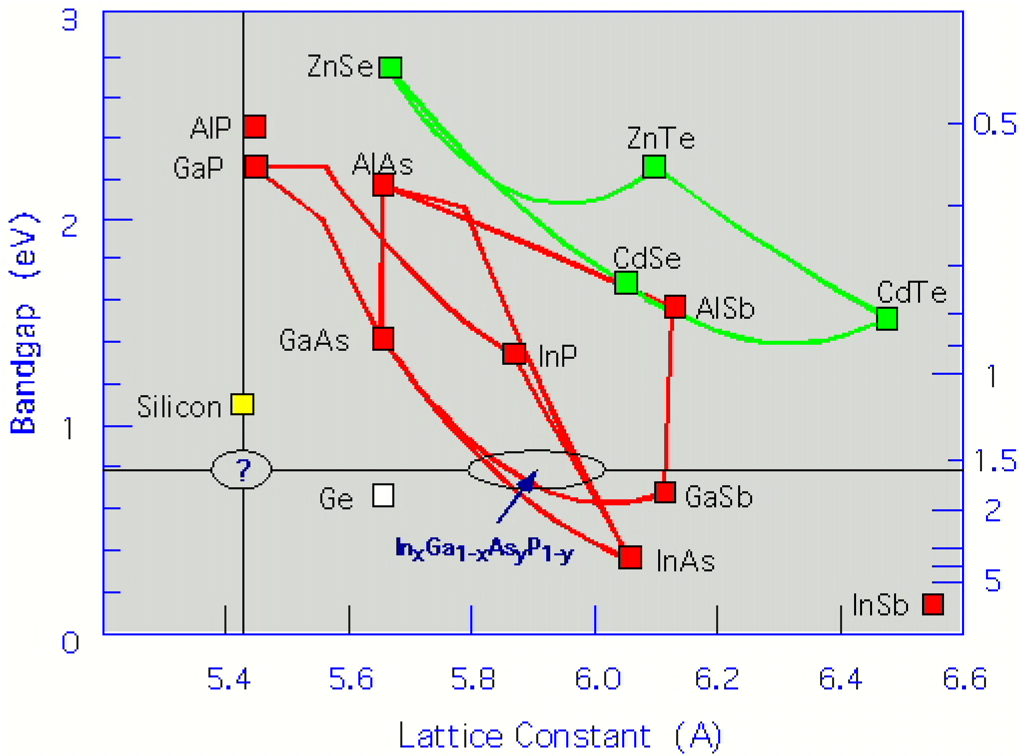






GaAs Band Structure




Bandgap (eV)
3
2
1
0
0.5
1
1.5
2
5
ZnSe
AlP
GaP
AlAs
ZnTe
CdSe
AlSb
CdTe
GaAs
InP
Silicon
?
Ge
GaSb
$In_xGa_{1-x}As_yP_{1-y}$
InAs
InSb
5.4
5.6
5.8
6.0
6.2
6.4
6.6
Lattice Constant (A)

Exciton in 3D

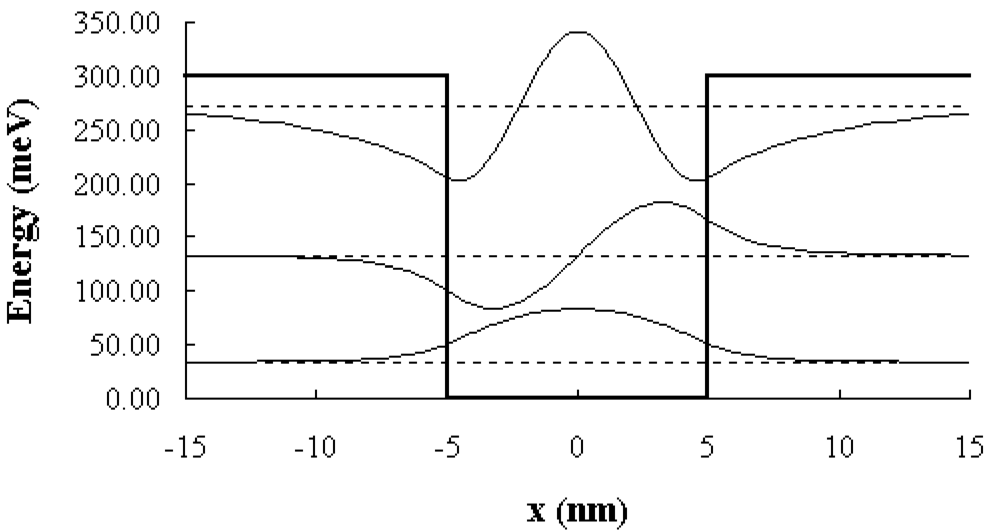
$$a_0 = 4\pi\epsilon_0\epsilon_b\hbar^2/e^2 m_0 m_{eh}$$

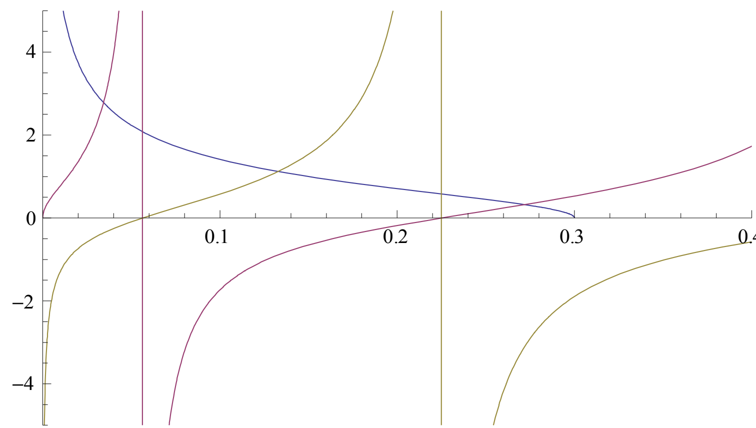
$$1/m_{eh} = 1/m_e + 1/m_h$$

$$E_n = E_g - \frac{R_{eh}}{n^2} \qquad R_{eh} = \frac{m_{eh}}{2}\left(\frac{e^2}{4\pi\epsilon_0\epsilon_b\hbar}\right)$$

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + V(x)\psi = E\psi \quad (1)$$

$$\frac{\sqrt{2\mathrm{m}(V-E)}}{\hbar} = \begin{cases} k\tan(ka) \\ -k\cot(ka) \end{cases}$$





m_e=0.067 m_0 in GaAs

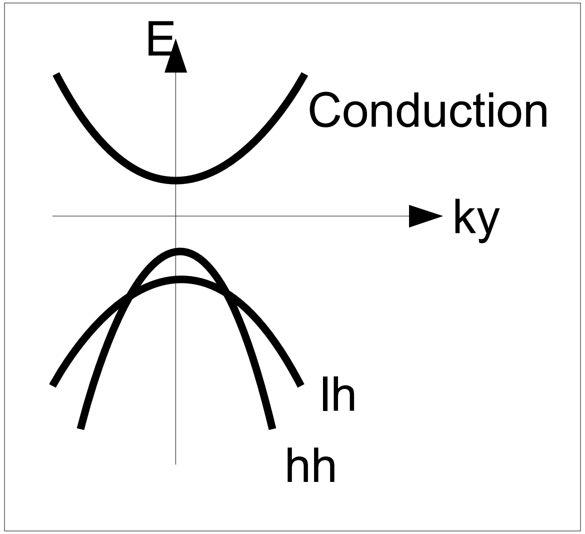
ΔEc ~ 0.2~0.3 eV for AlGaAs and GaAs

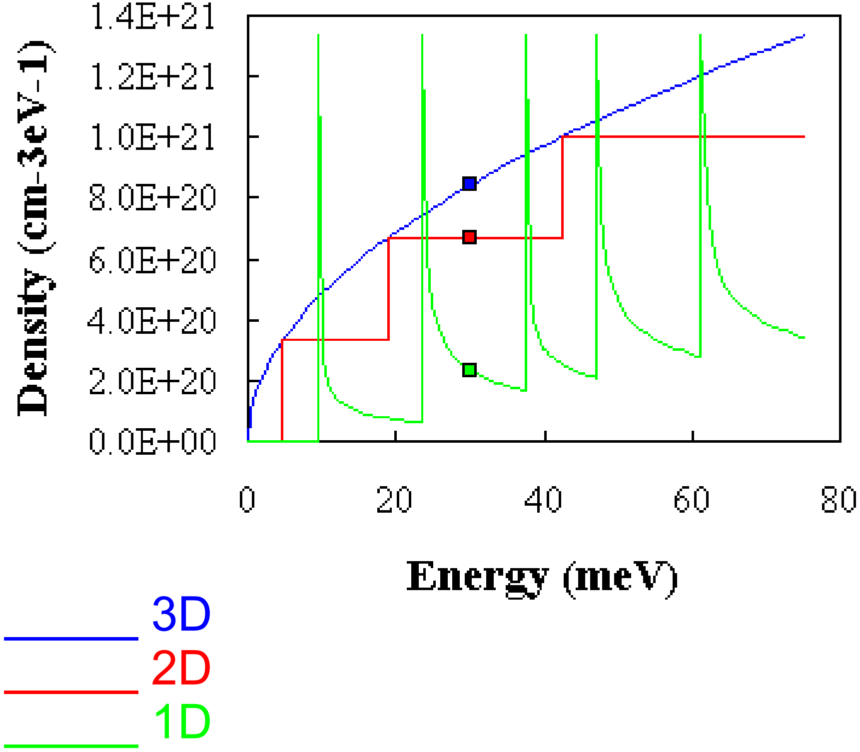
$$E_{bound} = E_{GaAs} + \frac{\hbar^2 \pi^2 n^2}{2 m_e a^2}$$

band gap of GaAs = 1.424 eV (300K) ~ 870nm

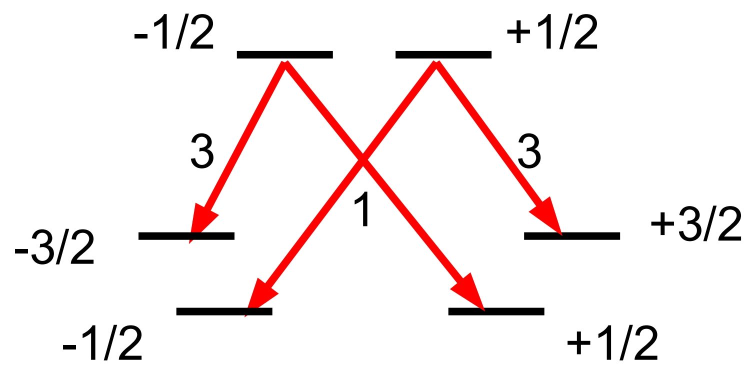
Useful data

room temp X-ionization, t~300 +/- 100 fs (GaAs QW)   < PRL 54, 1306 1985 >

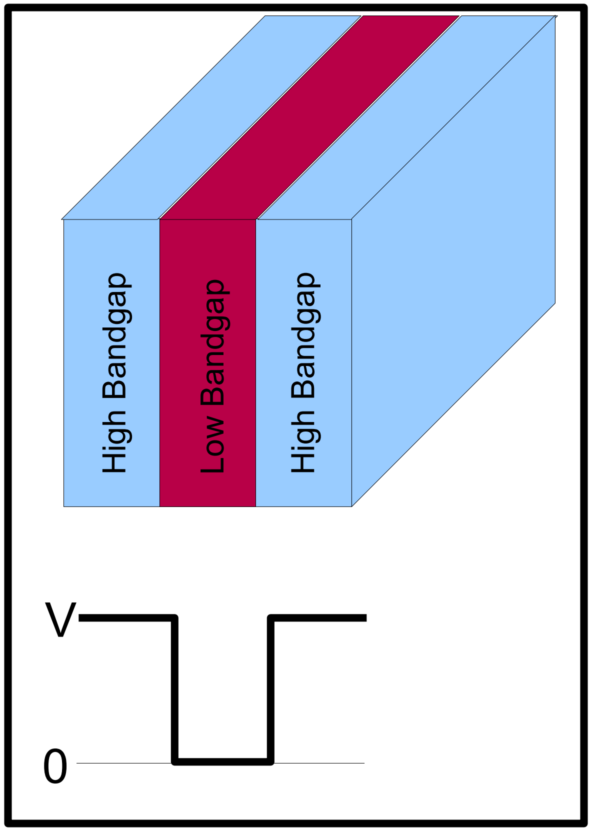




Density (cm-3eV-1)
1.4E+21
1.2E+21
1.0E+21
8.0E+20
6.0E+20
4.0E+20
2.0E+20
0.0E+00
0
20
40
60
80
Energy (meV)
3D
2D
1D



-1/2
+1/2
3
3
1
-3/2
+3/2
-1/2
+1/2



$$\frac{m}{\pi \hbar^2}$$