



EE 232 Lightwave Devices Lecture 15: Strained Quantum Well Laser

Reading: Chuang, Sec. 10.4
(There is also a good discussion in Coldren, Appendix 11)

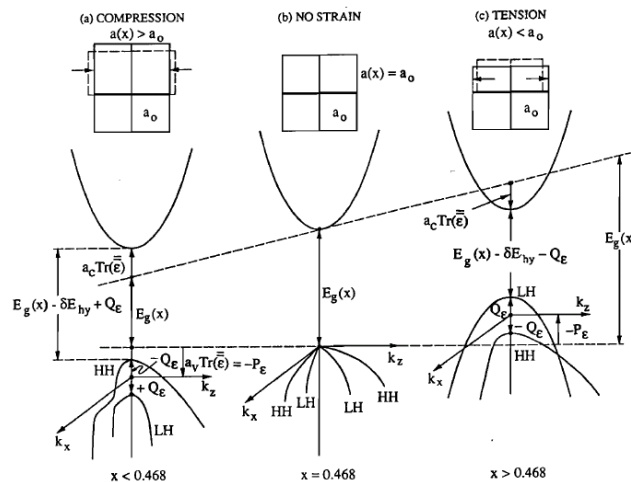
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Energy Band Structure for Strained GaInAs



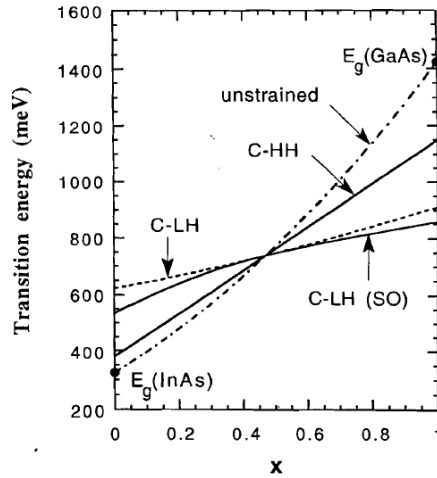
The energy-band structure in the momentum space for a bulk $\text{Ga}_x\text{In}_{1-x}\text{As}$ material under (a) biaxial compression, (b) lattice-matched condition, and (c) biaxial tension for different Ga mole fractions x . The heavy-hole band is above the light-hole band and its effective mass in the transverse plane (the k_x or k_y direction) is lighter than that of the light-hole band in the compressive strain case in (a). The light-hole band shifts above the heavy-hole band in the case of tension in (c).

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Energy Band Gap for Strained GaInAs



The energy band gap of a bulk $\text{In}_{1-x}\text{Ga}_x\text{As}$ vs. the Ga mole fraction x :
 — unstrained $\text{In}_{1-x}\text{Ga}_x\text{As}$; —, transition energies from the conduction band (C) to the heavy-hole (HH) and light-hole (LH) bands for a bulk $\text{In}_{1-x}\text{Ga}_x\text{As}$ pseudomorphically grown on InP; —, the conduction to light-hole transition energy calculated without the spin-orbit (SO) split-off band coupling.

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E-k Relation and Effective Masses

$$P_\varepsilon = -a_v(\varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz}) = -2a_v \left(1 - \frac{C_{12}}{C_{11}} \right) \varepsilon$$

$$Q_\varepsilon = -\frac{b}{2}(\varepsilon_{xx} + \varepsilon_{yy} - 2\varepsilon_{zz}) = -b \left(1 + 2 \frac{C_{12}}{C_{11}} \right) \varepsilon$$

$a = a_c - a_v$: hydrostatic potential

b : shear potential

$$E_{HH}(k) = -P_\varepsilon - Q_\varepsilon - \frac{\hbar^2}{2m_0} [(\gamma_1 + \gamma_2)k_t^2 + (\gamma_1 - 2\gamma_2)k_z^2]$$

$$E_{LH}(k) = -P_\varepsilon + Q_\varepsilon - \frac{\hbar^2}{2m_0} [(\gamma_1 - \gamma_2)k_t^2 + (\gamma_1 + 2\gamma_2)k_z^2]$$

$$m_{hh}^z = \frac{m_0}{\gamma_1 - 2\gamma_2} \quad m_{hh}^t = \frac{m_0}{\gamma_1 + \gamma_2}$$

$$m_{lh}^z = \frac{m_0}{\gamma_1 + 2\gamma_2} \quad m_{lh}^t = \frac{m_0}{\gamma_1 - \gamma_2}$$

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Table K.2 Important Band Structure Parameters*^{-f} for GaAs, AlAs, InAs, InP, and GaP

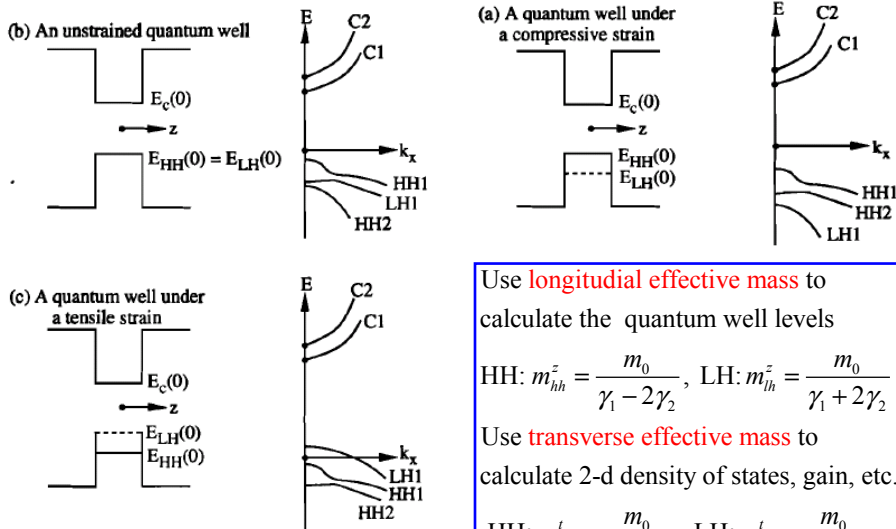
Parameters	Materials				
	GaAs	AlAs	InAs	InP	GaP
a_0 (Å)	5.6533	5.6600	6.0584	5.8688	5.4505
E_g (eV)					
0 K	1.519	3.13	0.42	1.424	2.90
300 K	1.424	2.229*	0.354	1.344	2.35*
Δ (eV)	0.34	3.03	0.28	0.11	0.08
$E_{c,sp}$ (eV)	-6.92	2.168*	0.38	-7.04	-7.40
Optical matrix parameter E_p (eV)	25.7	21.1	22.2	20.7	22.2
	(25.0) ^f			(16.7) ^f	
Deformation potentials (eV)					
a_c (eV)	-7.17	-5.64	-5.08	-5.04	-7.14
a_v (eV)	1.16	2.47	1.00	1.27	1.70
$a = a_c - a_v$ (eV)	-8.33	-8.11	-6.08	-6.31	-8.83
b (eV)	-1.7	-1.5	-1.8	-1.7	-1.8
d (eV)	-4.55	-3.4	-3.6	-5.6	-4.5
C_{11} (10^{11} dyne/cm ²)	11.879	12.5	8.329	10.11	14.05
C_{12} (10^{11} dyne/cm ²)	5.376	5.34	4.526	5.61	6.203
C_{44} (10^{11} dyne/cm ²)	5.94	5.42	3.96	4.56	7.033
Effective masses					
m_c^*/m_0	0.067	0.15	0.023	0.077	0.25
m_{hh}^*/m_0	0.50	0.79	0.40	0.60	0.67
m_{lh}^*/m_0	0.087	0.15	0.026	0.12	0.17
$m_{hh,z}/m_0 = \frac{1}{\gamma_1 - 2\gamma_2}$	0.333	0.478	0.263	0.606	0.326
$m_{lh,z}/m_0 = \frac{1}{\gamma_1 + 2\gamma_2}$	0.094	0.208	0.027	0.121	0.199
γ_1	6.8 (6.85)	3.45	20.4	4.95	4.05
γ_2	1.9 (2.1)	0.68	8.3	1.65	0.49
γ_3	2.73 (2.9)	1.29	9.1	2.35	1.25

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Band-Edge Profile and Subband Dispersion



Use longitudinal effective mass to calculate the quantum well levels

$$\text{HH: } m_{hh}^z = \frac{m_0}{\gamma_1 - 2\gamma_2}, \quad \text{LH: } m_{lh}^z = \frac{m_0}{\gamma_1 + 2\gamma_2}$$

Use transverse effective mass to calculate 2-d density of states, gain, etc.

$$\text{HH: } m_{hh}^t = \frac{m_0}{\gamma_1 + \gamma_2}, \quad \text{LH: } m_{lh}^t = \frac{m_0}{\gamma_1 - \gamma_2}$$

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