Quantum Well Gain (first sub-band)

$$g(\hbar\omega) = C_0 |\hat{e}\cdot\vec{P}_{cv}|^2 \rho_{r,2D}(\hbar\omega)\cdot H(\hbar\omega - E_{h1}^{e1})(f_c - f_v)$$

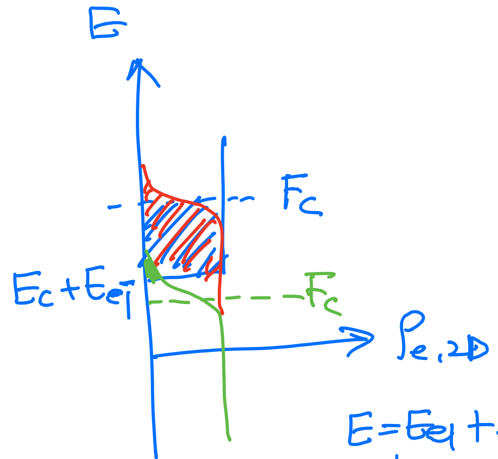
↑ Polarization dep ; ↑ $\frac{m_r^*}{\pi\hbar^2 L_z}$; ↑ step Function

In QW., first subband

$$n = N_1 = \int \rho_{e,2d}\cdot f_c \, dE = \int_0^\infty \frac{m_e^*}{\pi\hbar^2 L_z}\cdot\frac{dx}{1+e^x} \quad ; \quad x = \frac{E-F_c}{kT}$$

$$= n_c \ln\left(1 + e^{\frac{F_c - E_c - E_{e1}}{kT}}\right)$$

↑ $\frac{m_e^* k_B T}{\pi\hbar^2 L_z}$ effective D.O.S ↑ Lumped



$F_c \gg E_c + E_{e1}$

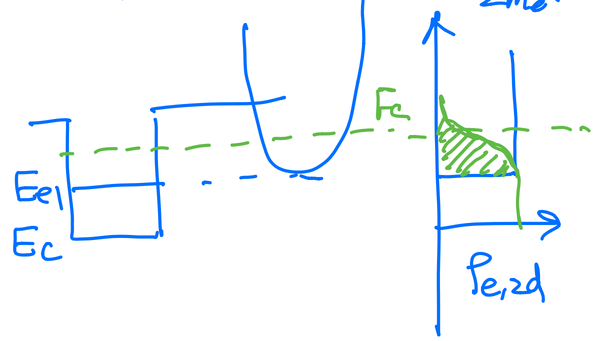
$$N_1 = n_c\cdot\frac{F_c - E_c - E_{e1}}{k_B T}$$

$F_c \ll E_c + E_{e1}$

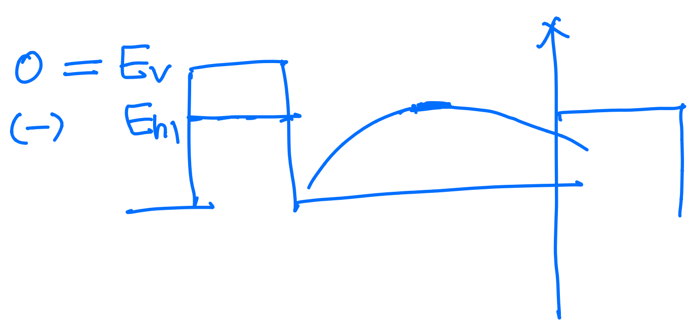
$$N_1 = n_c \ln(1+\epsilon) \simeq n_c \epsilon$$

$$= n_c e^{\frac{F_c - E_c - E_{e1}}{k_B T}}$$

$$E = E_{e1} + \frac{\hbar^2 k_t^2}{2m_e^*}$$



$$P = n_v\cdot\ln\left(1 + e^{\frac{E_{h1} - F_v}{kT}}\right)$$



Transparency in QW

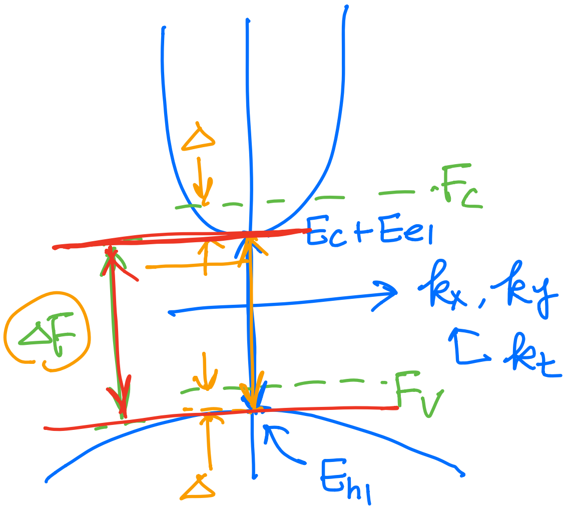
Bernard-Duraffourg cond. $\Longrightarrow$ $f_c = f_v \Rightarrow \Delta F = E_{g,eff}$

$g(\hbar\omega) \propto f_c - f_v$

Ref: $E_v = 0$

$\Delta F = F_c - F_v = E_g + (E_{e1} - E_{h1})$ ← E_c, (−)

Typical $\quad F_c - E_e - E_{e1} = F_v - E_{h1}$



$m_e^* \ll m_h^*$

$$N = n_c \cdot \frac{F_c - E_c - E_{e1}}{k_B T}$$

$$P = n_v \cdot e^{-\frac{F_F - E_{h1}}{k_B T}}$$

Charge neutrality

$N = P$

$$\Delta = \frac{F_c - E_c - E_{e1}}{k_B T} = \frac{E_F - E_{h1}}{k_B T}$$

$$n_c \cdot \Delta = n_v \cdot e^{-\Delta}$$

$$m_e^* \Delta = m_h^* e^{-\Delta}$$

$$\Delta = \left(\frac{m_h^*}{m_e^*}\right) e^{-\Delta}$$

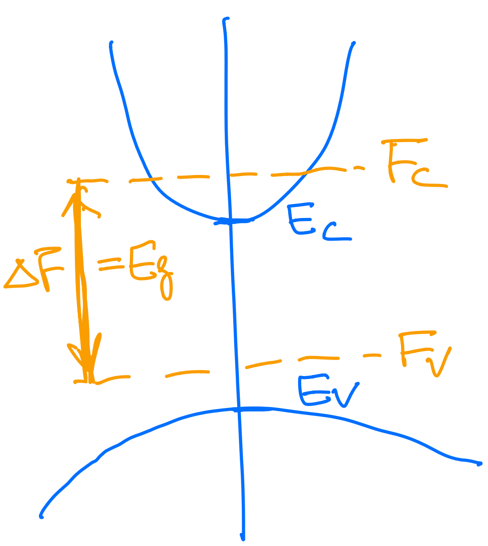
For GaAs $\quad m_e^* = 0.067\, m_0$

$m_h^* = 0.5\, m_0$

$\Delta = 1.56$

$N = n_c \cdot \Delta \approx 10^{18}\ cm^{-3}$

Review B-D for Bulk



$m_e^* < m_h^*$

$$\begin{cases} N = n_{c,bulk} \cdot \frac{4}{3\sqrt{\pi}} \Delta^{3/2} \\ P = n_{v,bulk} \cdot e^{-\Delta} \end{cases}$$

Bernard-Duraffourg

$$\Delta = \frac{F_c - E_c}{k_B T}$$

$$\Delta = \frac{F_v - E_v}{k_B T}$$

$$n_{c,bulk} = 2\left(\frac{\pi m_e^* k_B T}{2\pi^2 \hbar^2}\right)^{3/2}$$

$N = P$

$$m_e^{*\frac{3}{2}} \cdot \frac{4}{3\sqrt{\pi}} \Delta^{3/2} = m_h^{*\frac{3}{2}} e^{-\Delta}$$

GaAs : $\Delta = 2.15$, $N = 9\times10^{17}\ cm^{-3}$

* No significant difference in N_{tr} in Bulk or QW

↑ Transparency carrier conc.

General $J = (A)N + (B)N^2 + (C)N^3$

↑ current density

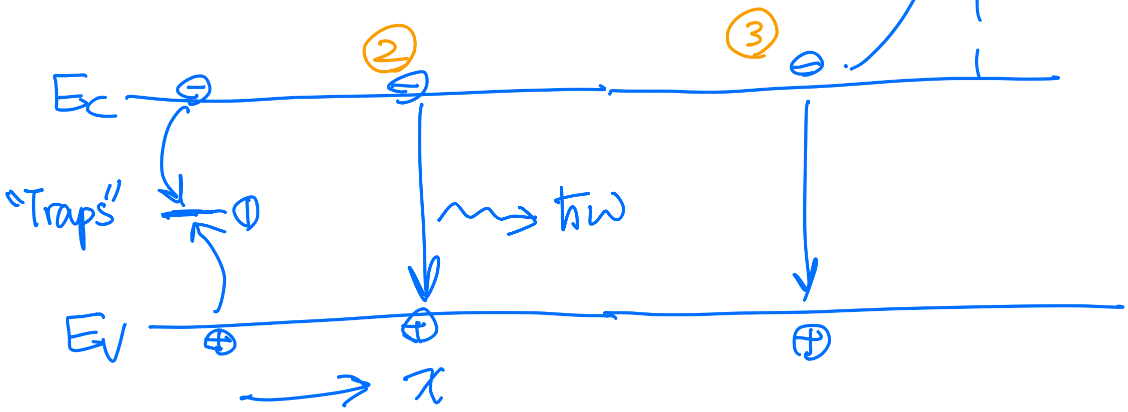
$N > N_{tr}$

① SRH (Non-radiative) recombination

② Radiative recombination

③ Auger Recomb.

e^- energetic elec.



$J \propto CN^3$ in Typical InGaAsP laser at NIR $\lambda \sim 1.55\mu m$

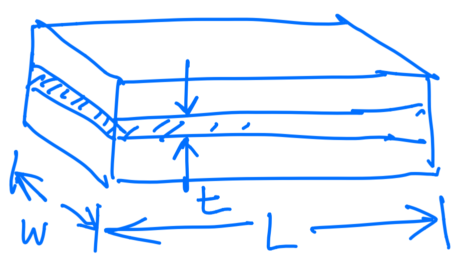
Reduce Power consumption

$P_{cons} = V\cdot I \propto V\cdot Area\cdot CN^3 > V\cdot Area\cdot CN_{tr}^3$

Threshold current . when $N = N_{th} > N_{tr}$

$I = \frac{N_{th}\cdot V_{active}}{\tau}\cdot q$

τ ← carrier lifetime



Bulk $V_{active} = W\cdot L\cdot t$, $t \sim 100\ nm$

QW $V_{active} = W \cdot L \cdot L_z$, $L_z < 10$ nm

→ Have lower threshold current

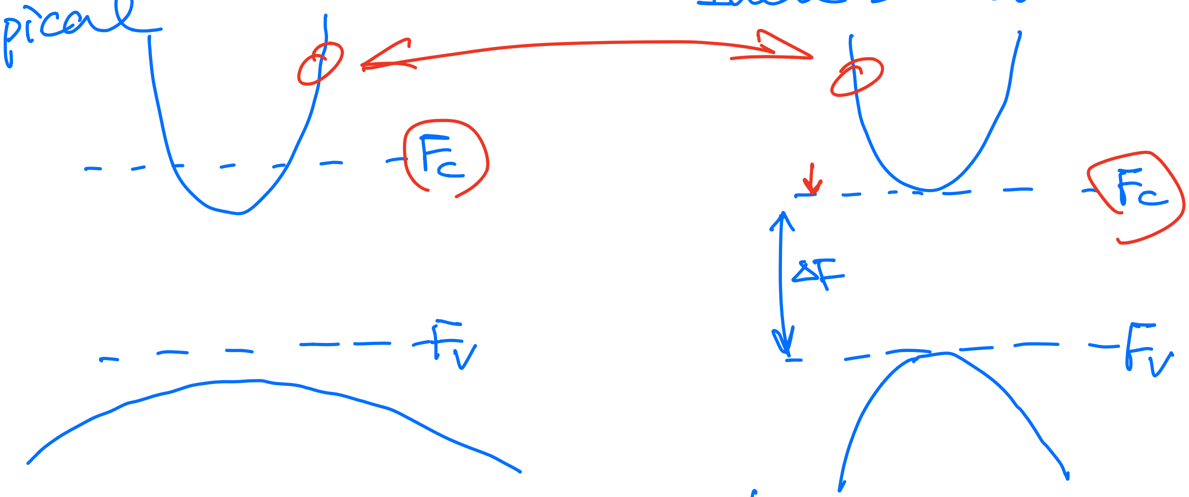
Lower Power consumption

⇒ Almost all lasers are QW

Strained Quantum Well Lasers:

Typical

Ideal Semiconductor



$m_e^* \ll m_h^*$ $m_e^* = m_h^*$

N_{tr}(Ideal) < N_{tr}(typic

$$n_s = N_1 \cdot L_z = \frac{m_e^* k_B T}{\pi \hbar^2} \ln\left(1 + e^{F_c - E_c - E_{e1}}\right)$$

$\left[\frac{1}{cm^2}\right]$

$$F_c = E_c + E_{e1}$$

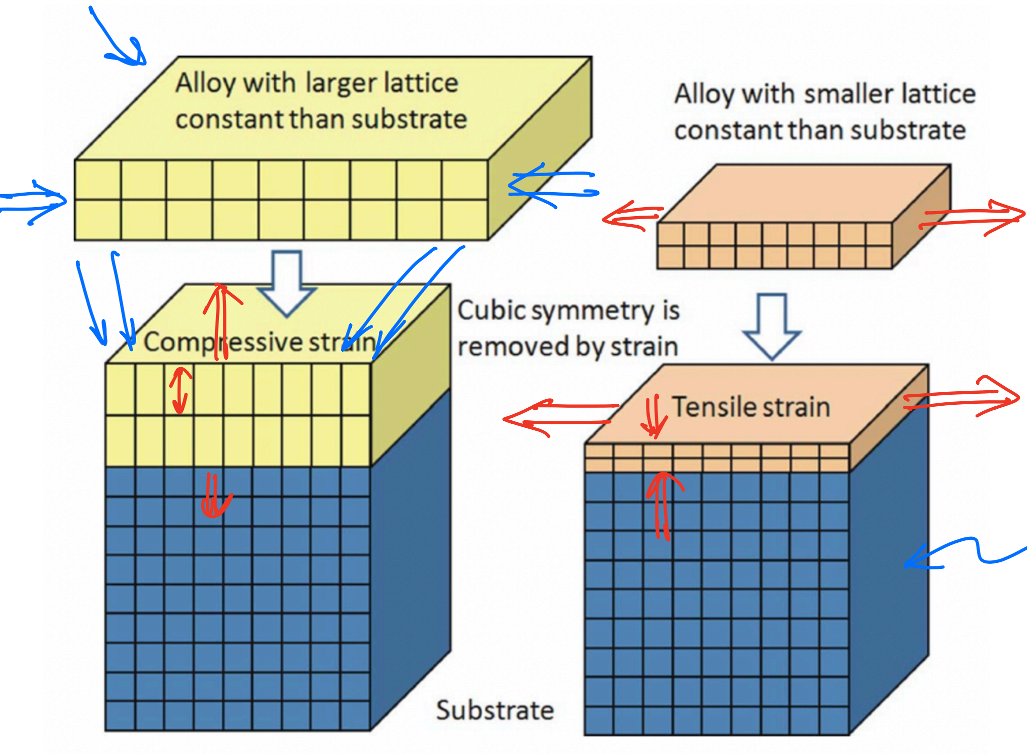
$$n_s = n_c \cdot L_z \cdot \ln 2 = \frac{m_e^* k_B T}{\pi \hbar^2} \ln 2$$

Previously. $n_s(\text{GaAs}) = \frac{m_e^* k_B T}{\pi \hbar^2} \times 1.56$

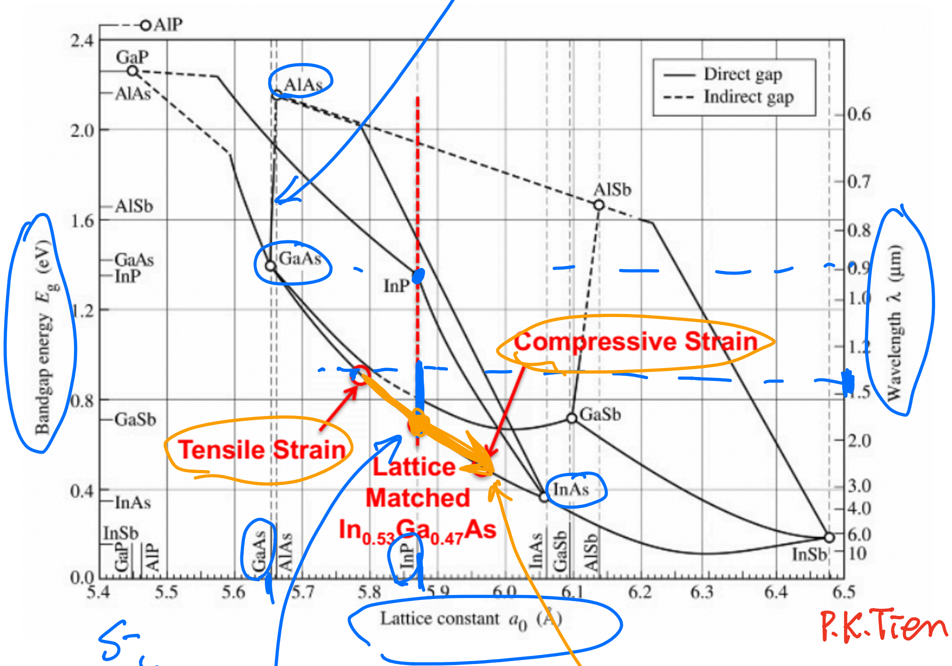
$$\frac{n_{s,tr,typical}}{n_{s,tr,ideal}} = \frac{1.56}{\ln 2} \approx 2$$

$J \propto C N^3$. 2x reduction in N

⇒ 8x reduction in current.



$(AlAs)_x(GaAs)_{1-x} = Al_xGa_{1-x}As$



5.c

P.K.Tien

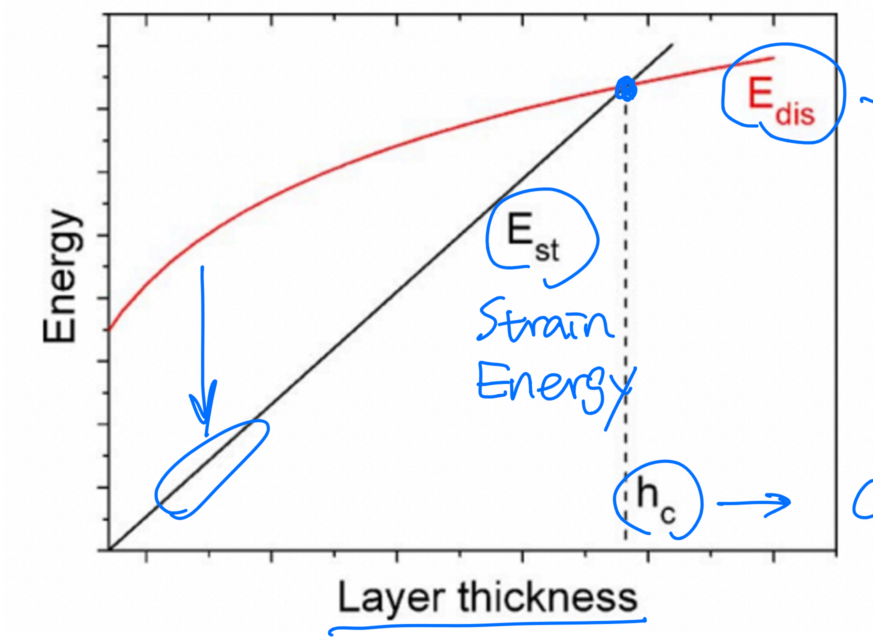
GaAs → 870 nm

→ 1310 nm
1550 nm

Compressive

$(In_{0.5}Ga_{0.5}As)_y + InP_{1-y} \rightarrow InGaAsP$

$In_xGa_{1-x}As_yP_{1-y}$



→ Dislocation

→ Critical thickness

"Coherent" strain

↳ like rubberband

"Relaxed"

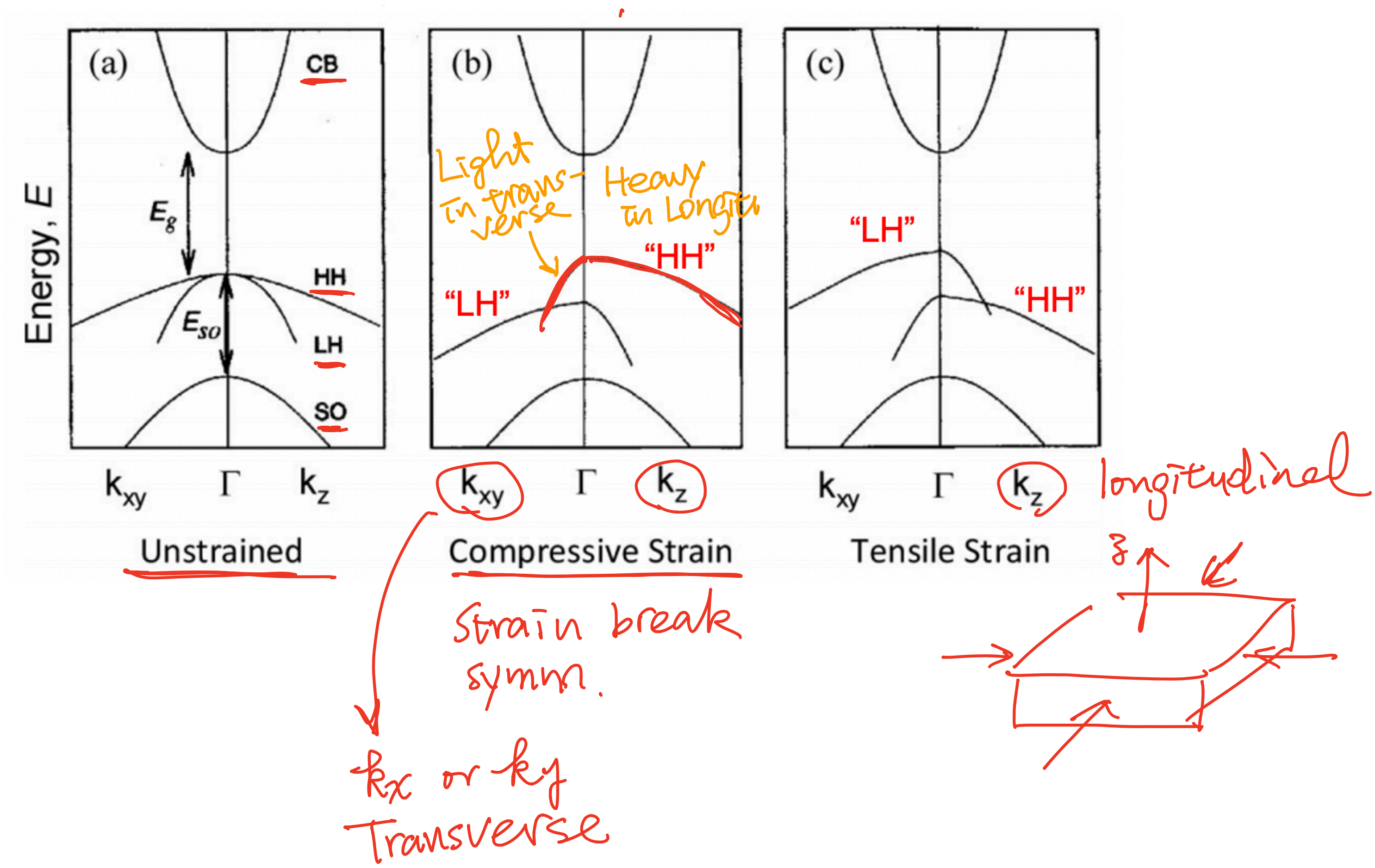
Strain change energy band, valence band

→ ← Compress   Eg ↗ E_c / E_v

HH ↑
LH ↓

Tensile   Eg ↘

HH ↓
LH ↑


(a)
(b)
(c)
CB
HH
LH
SO
Energy, E
E_g
E_{so}
"LH"
"HH"
k_{xy}
Γ
k_z
Unstrained
Compressive Strain
Tensile Strain
Light in trans-verse
Heavy in Longitu
Strain break symm.
kx or ky Transverse
longitudinal
z