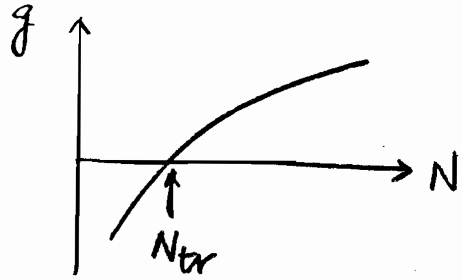
# Strained Quantum Wells




$g = g_0 \cdot \ln \frac{N}{N_{tr}}$ for QW $\qquad$ $g = a(N - N_{tr})$ for Bulk

$g_{th} = g_0 \ln \frac{N_{th}}{N_{tr}}$ $\qquad$ $g_{th} = a(N_{th} - N_{tr})$

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

$\hookrightarrow \tau = \tau(N_{th})$

$N_{tr}(QW) \sim N_{tr}(Bulk)$

Reduction in threshold is mainly from the reduction in active volume (i.e. thickness)

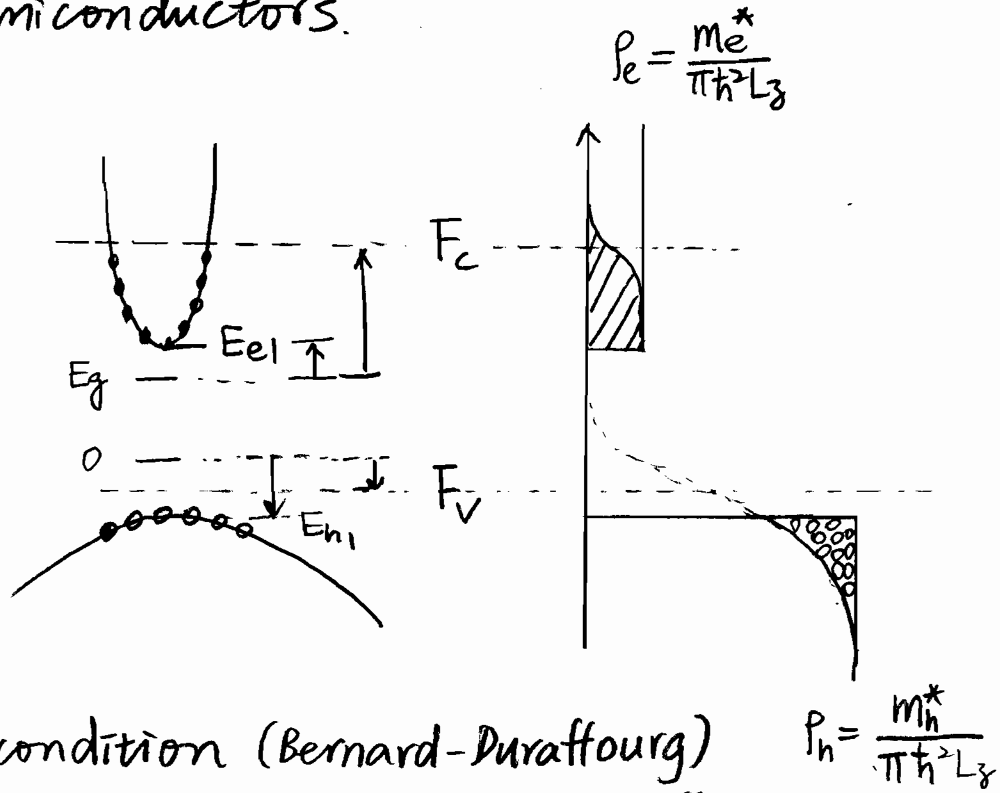
If $N_{tr}$ can be reduced $\longrightarrow$ Further reduction of $I_{th}$.

What determines $N_{tr}$ ?

# Influence of Effective Mass

In most semiconductors.

$m_h^* \gg m_e^*$




Population condition (Bernard-Duraffourg)

$$F_c - F_v + E_g > \hbar\omega > E_g + E_{e1} - E_{h1} \quad (\equiv E_g^{eff})$$

*Note: The reference for $F_c$, $E_{e1}$ is $E_g$
The reference for $F_v$, $E_{h1}$ is $E_v = 0$

Since $m_h^* \gg m_e^*$, $F_v$ usually above $E_{h1}$,

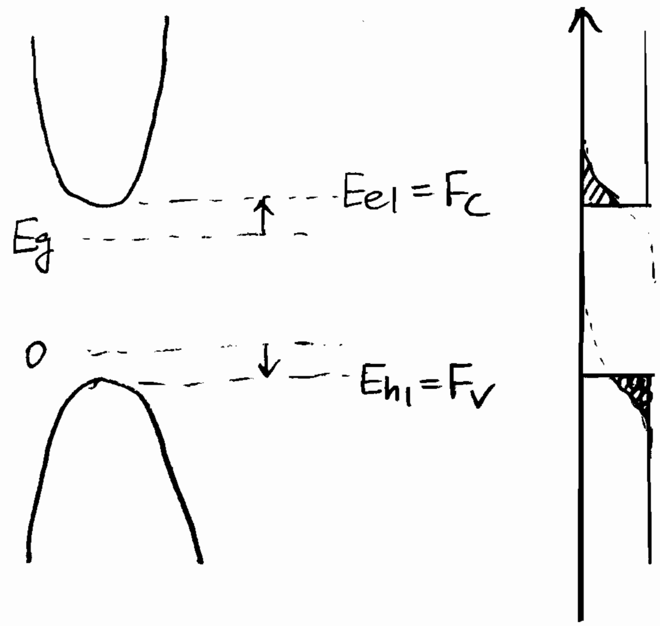
$N_{tr}$, the carrier concentration required to reach

$$F_c - F_v + E_g \geq E_g + E_{e1} - E_{h1}$$

is large.

Ideal semiconductor

$m_h^* = m_e^*$

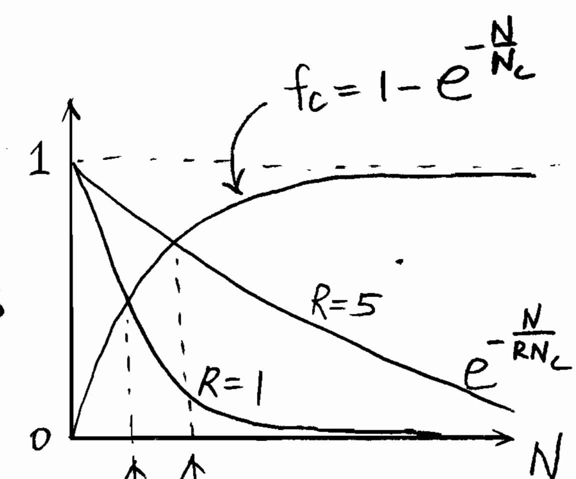


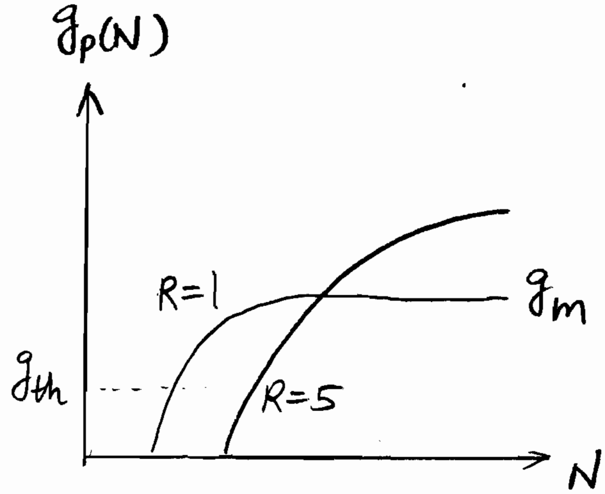

Mathematically

$$g_p(N) = g_m (f_c - f_v)$$

$$\approx g_m (1 - e^{-N/N_c} - e^{-N/RN_c})$$

$$R = \frac{m_h^*}{m_e^*}$$

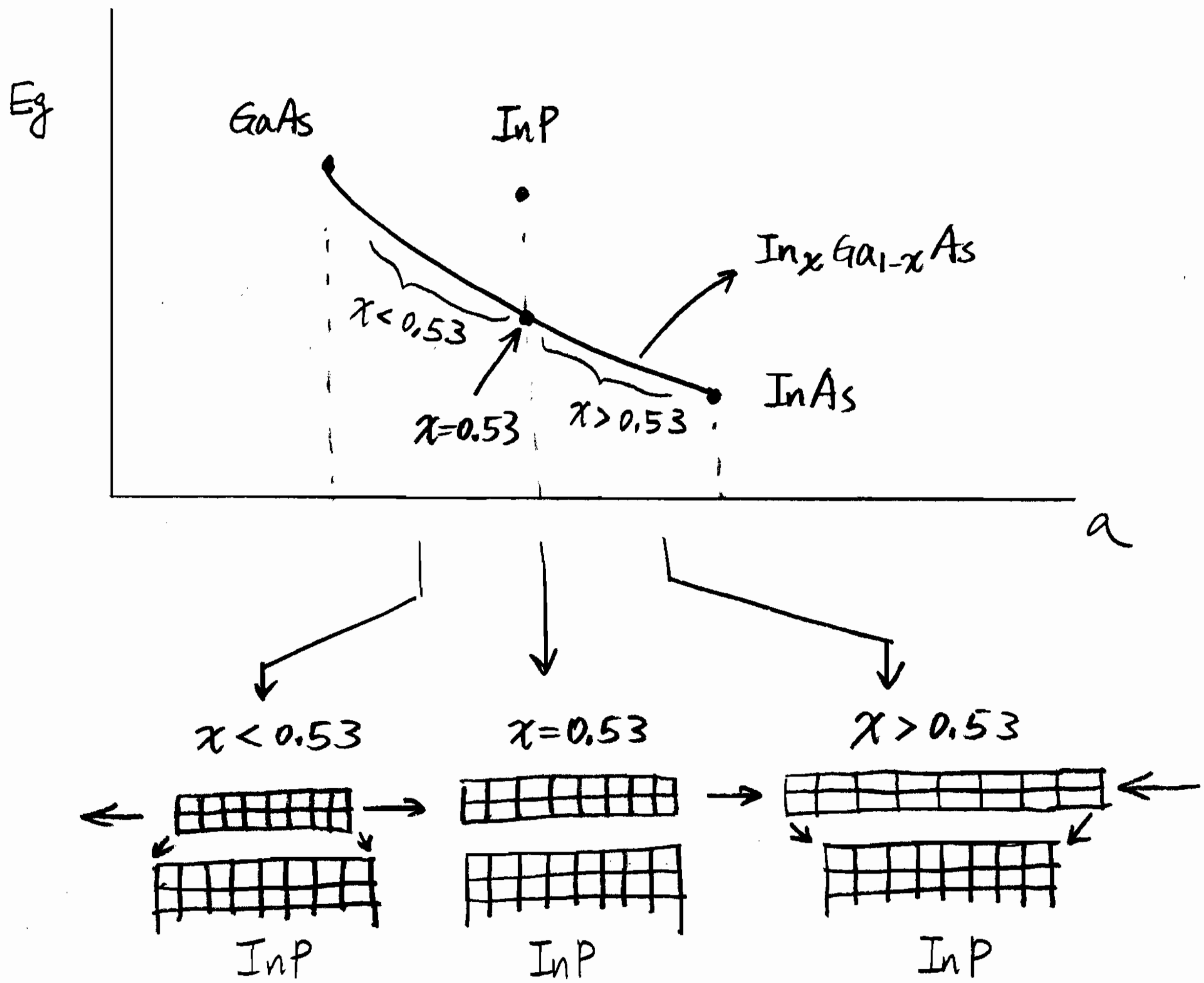



for $g_{th} \ll g_m$

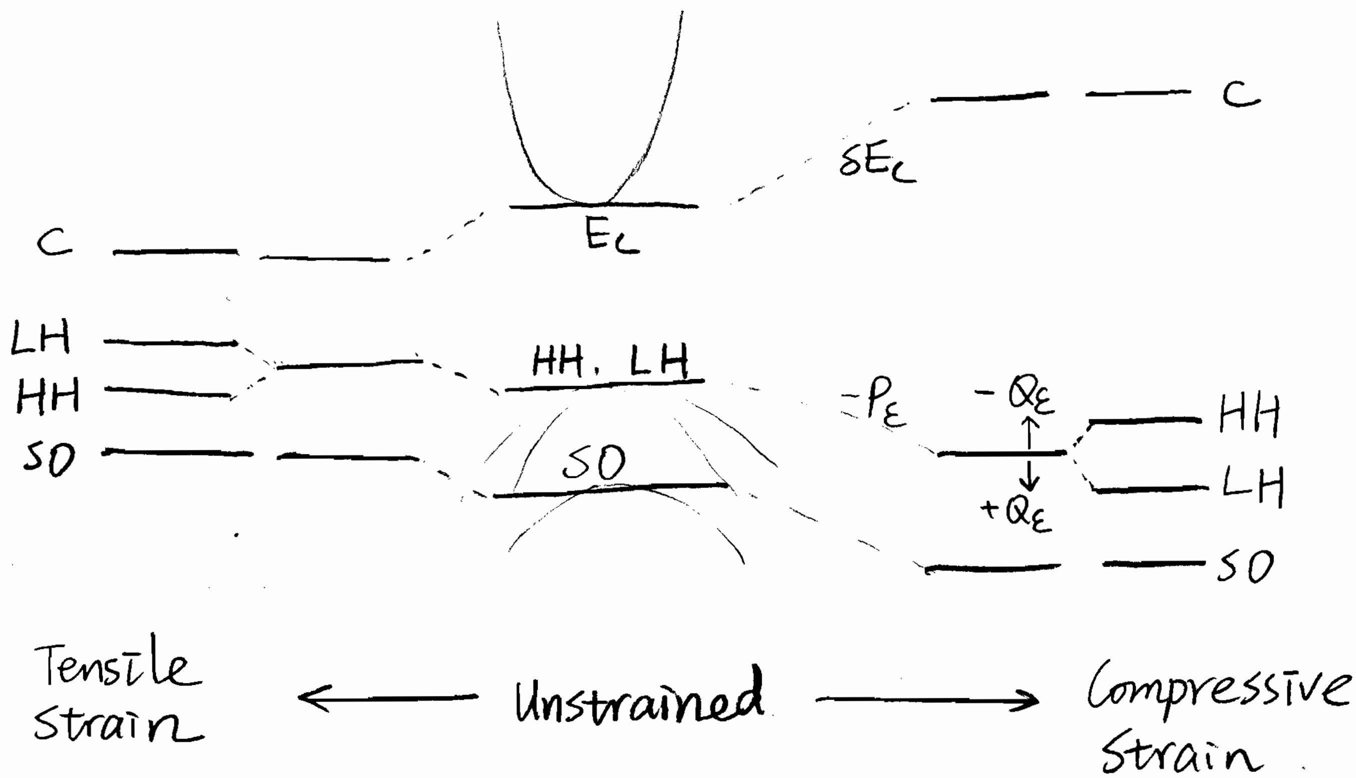
R=1 has lower $N_{th}$ than R=5

# Strain Effect




$In_xGa_{1-x}As$ experience "tensile" strain

$In_xGa_{1-x}As$ experience "compressive" strain




Ref. [ Chuang pp. 440 – 448; Coldren pp. 530 – 536 ]

Strain $$\varepsilon = \varepsilon_{xx} = \varepsilon_{yy} = \frac{a_0 - a(x)}{a_0}$$

$a_0$ : lattice constant of InP.

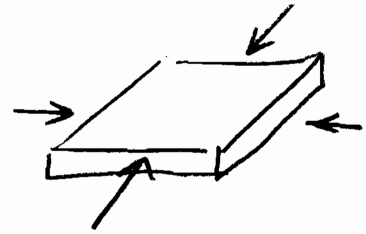
$$\begin{cases} \varepsilon < 0 & \text{for compressive strain} \\ \varepsilon > 0 & \text{" tensile "} \end{cases}$$

$$\varepsilon_\perp = \varepsilon_{zz} = -2\frac{C_{12}}{C_{11}}\varepsilon$$

↑
Compliance Tensor

$C_{12} \approx 0.5 C_{11}$

$$\begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{12} \\ C_{12} & C_{11} & C_{12} \\ C_{12} & C_{12} & C_{11} \end{bmatrix} \begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \end{bmatrix}$$



uniaxial stress

$$\sigma_{xx} = \sigma_{yy} = \sigma$$

$$\sigma_{zz} = 0$$

$$\varepsilon_{xx} = \varepsilon_{yy} = \varepsilon$$

$$\sigma_{zz} = 0 \Rightarrow C_{12}\varepsilon_{xx} + C_{12}\varepsilon_{yy} + C_{11}\varepsilon_{zz} = 0$$

$$\varepsilon_{zz} = -2\frac{C_{12}}{C_{11}}\varepsilon$$

Band Edge shift:

$$E_c = E_g(x) + \delta E_c$$

$$E_{HH} = -P_\varepsilon - Q_\varepsilon$$

$$E_{LH} = -P_\varepsilon + Q_\varepsilon$$

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

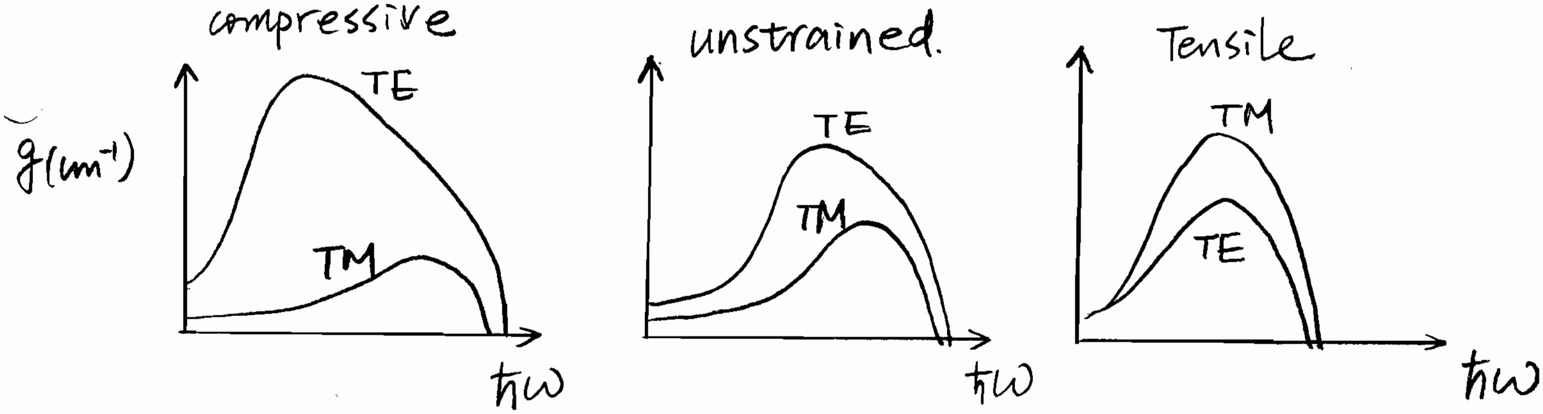
$$P_\varepsilon = -a_v(\varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz}) = -2a_v\left(1 - \frac{C_{12}}{C_{11}}\right)\varepsilon$$

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

$a = a_c - a_v$ : hydrostatic potential

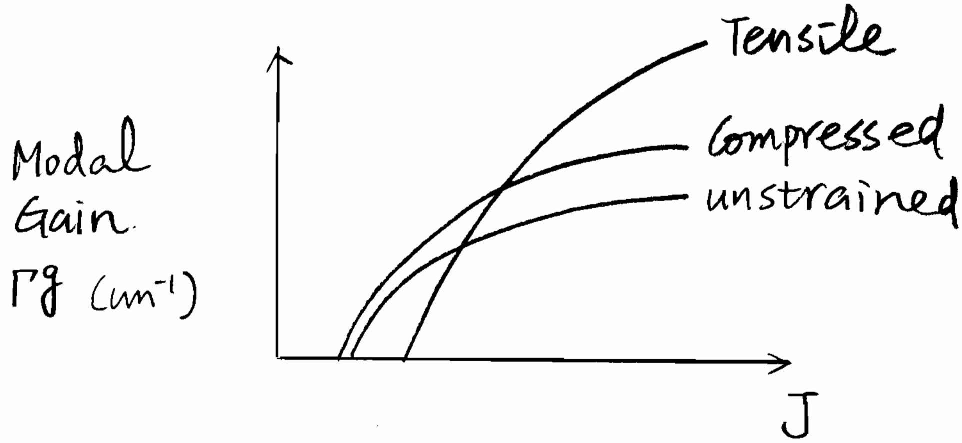
$b$ : shear potential

## Gain Spectra




Compressive strained and unstrained QW laser are TE polarized.

Tensile strained QW laser is TM polarized.




Compressive $\longrightarrow$ low threshold

Tensile $\longrightarrow$ high gain (for semiconductor optical amplifier, SOA)