11/15/05 ECE 6440

Carrier-effect modulation - change in abs + refr. due to carrier density

Drude-Lorenz model

$$\Delta\alpha = \frac{e^3 \lambda_0^2}{4\pi^2 c^3 \varepsilon_0 n}\left[\frac{N_e}{\mu_e (m_{ce}^*)^2} + \frac{N_h}{\mu_h (m_{ch}^*)^2}\right]$$

e = electron charge
N = carrier density
μ = mobility
m^* = reduced mass

$$\Delta n = -\frac{e^2 \lambda_0}{8\pi^2 c^2 \varepsilon_0 n}\left(\frac{N_e}{m_{ce}^*} + \frac{N_h}{m_{ch}^*}\right)$$

@ $1.3\,\mu m = \lambda_0$

$$\Delta\alpha = 6\times10^{-18}\Delta N_e + 4\times10^{-18}\Delta N_h$$
$$\Delta n = -\left[6.2\times10^{-22}\Delta N_e + 6\times10^{-18}(\Delta N_h)^{0.8}\right]$$

@ $\lambda_0 = 1.55\,\mu m$

$$\Delta\alpha = 8.5\times10^{-18}\Delta N_e + 6\times10^{-18}\Delta N_h$$
$$\Delta n = -\left[8.8\times10^{-22}\Delta N_e + 8.5\times10^{-18}(\Delta N_h)^{0.8}\right]$$

Carrier generation via optical absorption

$$\frac{dN}{dt} = \frac{P\eta}{h\nu} - \frac{N}{\tau_0}$$

τ_0 = recombination time, 1-10ns (depends on N)
P = optical power
η = abs. quantum efficiency

$$N = \frac{P\eta}{h\nu}\tau_0$$ @ steady-state

$\lambda = 1.15\,\mu m$ $\quad \alpha = 2.83\, dB/cm$ $\quad \eta = \frac{P_{out}}{P_{in}} = 1 - 10^{-.283(.01)}$ $= 0.64\%$ $\quad 100\mu m$

$\lambda = 1.55\,\mu m$ $\quad \alpha = 0.004\, dB/cm$ $\quad \eta = 0$

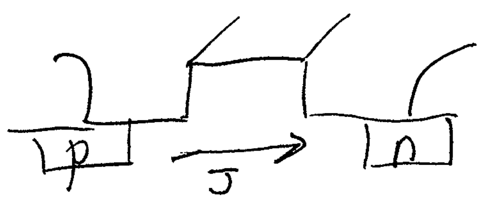
$\lambda < 1\,\mu m$ $\quad \alpha \geq 10^2\, cm^{-1}$ $\quad \eta \geq 60\%$

two-photon absorption

$$\frac{dN}{dt} = \frac{\beta_2 I^2}{2\hbar\nu} - N/\tau \quad @ \text{ steady-state } \quad N = \tau\beta_2 I^2/2\hbar\nu$$

$$\beta_2 \sim 7\times10^{-10}\ cm/W \quad @\ 1550\ nm \text{ in Si}$$

current injection



$$\frac{dN}{dt} = \frac{J}{e} - \frac{N}{\tau} \quad @ \text{ steady-state } \quad N = \frac{J}{e}\tau$$

modulation response $N = N_0 + N_1 e^{jft} \longrightarrow J = J_0 + J_1 e^{jft}$

$$\cancel{jfN_1 e^{jft} = \frac{N_0}{e} + \frac{N_1 e^{jft}}{e} - \frac{N_0}{\tau} - \frac{N_1}{\tau} e^{jft}}$$

$$\cancel{jfN_1 = \frac{N_1}{e} - \frac{N_1}{\tau}}$$

$$jfN_1 e^{jft} = \cancel{\frac{J_0}{e}} + \frac{J_1}{e}\cancel{e^{jft}} - \cancel{\frac{N_0}{\tau}} - \frac{N_1}{\tau}\cancel{e^{jft}}$$

$$\left(jf + \frac{1}{\tau}\right)N_1 = \frac{J_1}{e} \Rightarrow N_1 = \Delta N(t) = \frac{J_1}{e\left(jf+\frac{1}{\tau}\right)}$$

$$\Delta N(t) = \frac{J_1\tau}{e}\cdot\frac{1}{(1+jf\tau)} = \frac{J_1\tau}{e}\cdot\frac{1-jf\tau}{1+(f\tau)^2}$$

3 dB bandwidth for $1/\tau \sim 1\,GHz$