# Gain and Absorption

ECE 162C

Lecture #7

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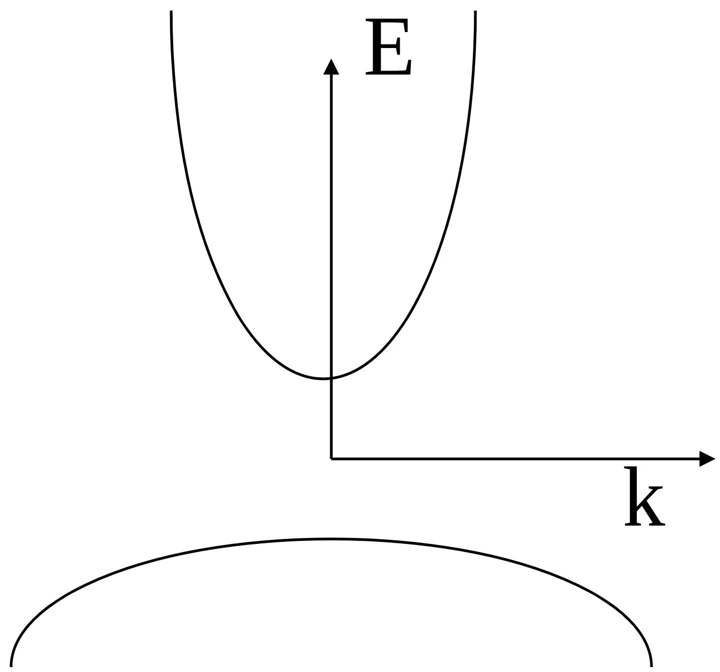
Read Kasip, Chapter 3

Midterm: May 5. Chapters 1-4

# Bands

- Direct bandgap: Minimum of conduction band and maximum of valence band occur at the same point in k space, typically k=0 (defined as Γ).

$$E = \frac{\hbar^2 k^2}{2m_e}$$



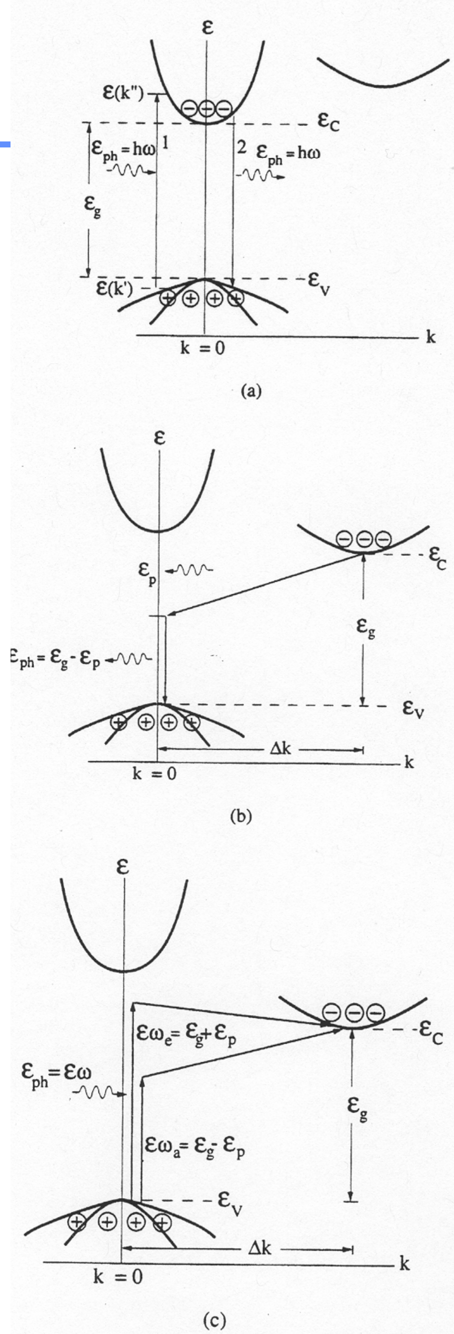
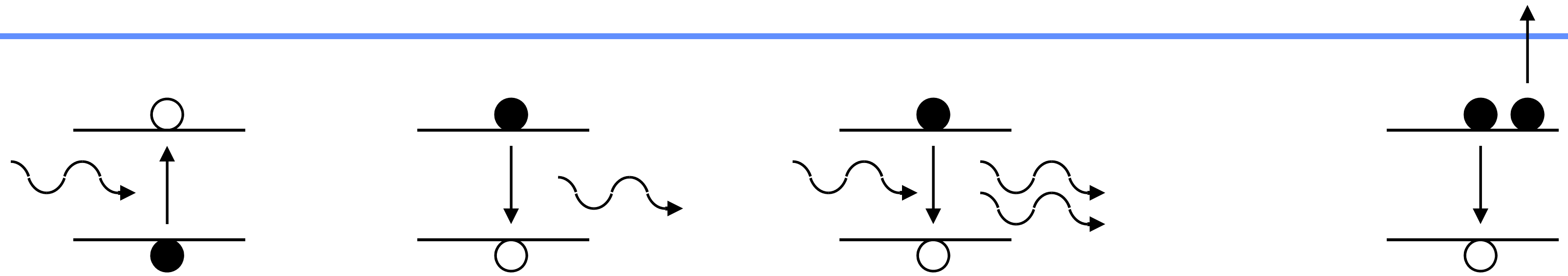



**Figure 3.2** Illustration of band-to-band of absorption and recombination processes in (a) direct bandgap semiconductor and (b) and (c) indirect bandgap semiconductor.

Si: Indirect gap.

Hence, a phonon is required to conserve momentum. Less likely to occur. Lower gain and absorption (except at higher energies).

# Electronic transitions



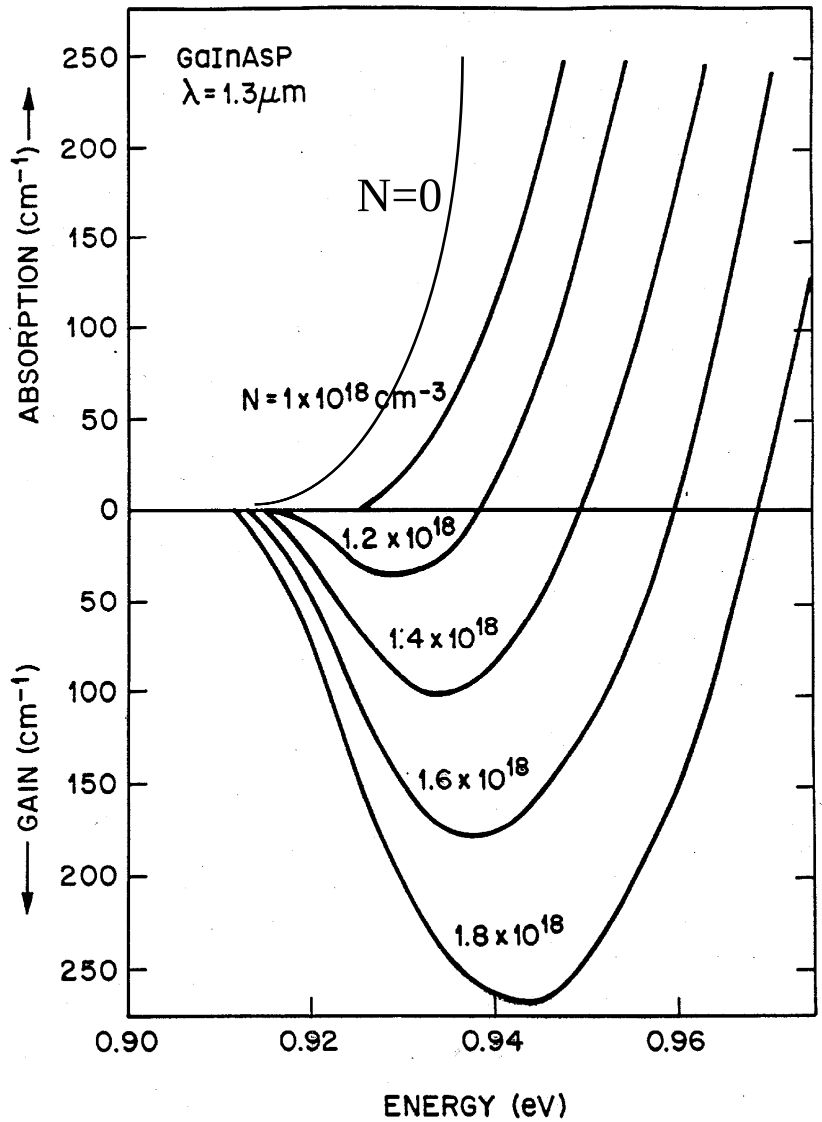
$R_{nr}$

- $R_{12}$: absorption of a photon
- $R_{sp}$: spontaneous emission of a photon
- $R_{21}$: stimulated emission of a photon
- $R_{nr}$: nonradiative recombination (Auger, trap, etc.)

# Material Gain

Calculated gain curves for InGaAsP/InP laser operating at 1.3μm

- Gain peak moves to shorter wavelengths with higher pumping
- Higher differential gain for wavelengths shorter than the gain peak




N.K. Dutta, J. Appl. Phys., **51**, 6095 (1980)

# Gain

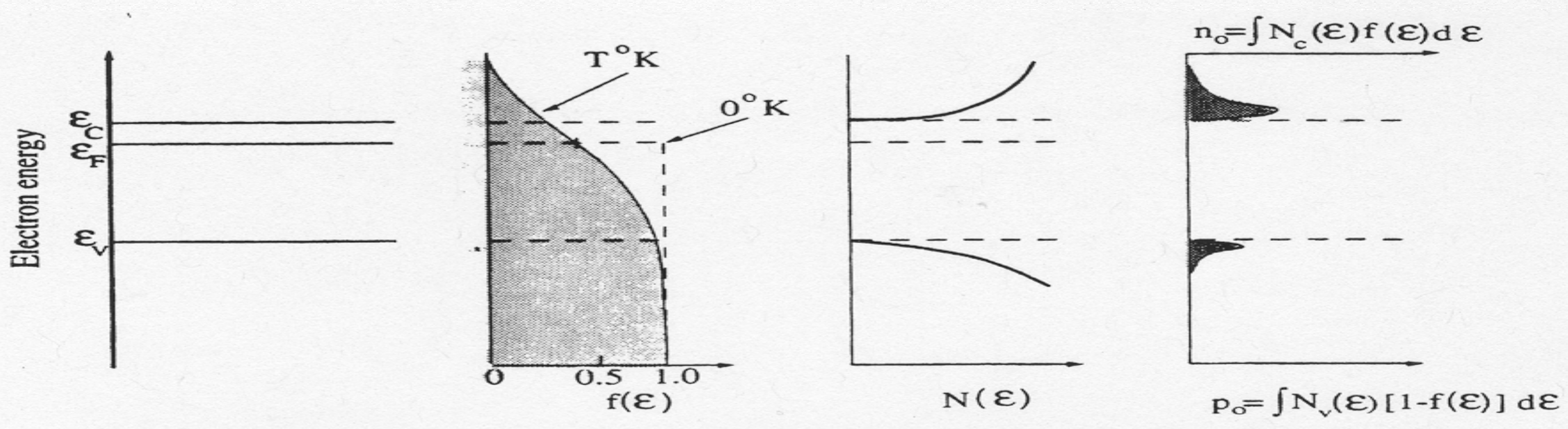



**Figure 2.18** Distribution functions, density-of-states functions, and carrier distributions (in energy) in an n-type nondegenerate semiconductor.

High gain requires

1) upper level full (f~1)

2) lower level empty (f~0)

$$f(E) = \frac{1}{1 + e^{(E - E_F)/kT}}$$

# Quasi Fermi Levels

$$n = n_i e^{(E_{Fn} - E_i)/kT}$$

$$p = n_i e^{-(E_{Fp} - E_i)/kT}$$

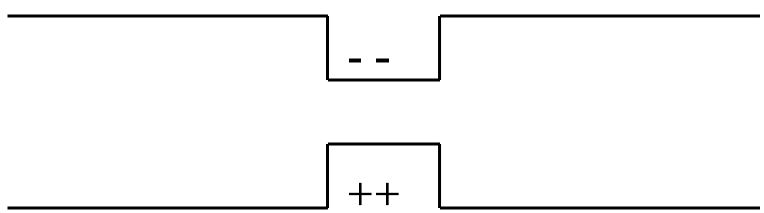
$$pn = n_i^2 e^{(E_{Fn} - E_{Fp})/kT}$$

- Gain occurs when

$$g(\hbar\omega) > 0 \quad when \quad E_{Fn} - E_{Fp} > \hbar\omega$$

# Double Heterostructure Lasers (Kroemer)

- Carriers diffuse away so it is difficult to get high gain
- A method of confining the carriers to a region in space is necessary
- Double heterostructure (proposed in 1964 but not implemented until 1968, which led to the first cw lasers).



# Lasing threshold

$r_1$ is the amplitude reflection coefficient.

$R_1$ is the power reflection coefficient

R is the average power reflection coefficient

$$R_1 = r_1^{\,2}$$

$$R = \sqrt{R_1 R_2} = r_1 r_2$$

$$R_1 R_2 e^{(\Gamma g_{th} - \alpha_i)2L} = 1$$

$$\Gamma g_{th} = \alpha_i + \frac{1}{2L} \ln \frac{1}{R_1 R_2}$$

$$\Gamma g_{th} = \alpha_i + \alpha_m = \alpha_T$$

$$\alpha_m = \frac{1}{2L} \ln \frac{1}{R_1 R_2} = \frac{1}{L} \ln \frac{1}{R}$$

$R = 0.32$ (typical for InGaAsP or GaAs Lasers)

# Round trip phase

- Round trip phase must be a multiple of pi.
- The round trip cavity length must be a multiple of the wavelength

$$m\lambda = 2nL$$

- The spacing between modes is

$$\Delta\lambda = \frac{\lambda^2}{2n_g L}$$

# Solve Wave Equation for Symmetric Guide

$$e(x,y,z,t) = \mathrm{Re}[E(x,y,z)e^{i\omega t}]$$

$$\nabla^2\vec{E} + \omega^2\mu\varepsilon\vec{E} = 0$$

$$\boxed{\nabla^2\vec{E} + k^2\vec{E} = 0}$$

*where*

$$k = \omega\sqrt{\mu\varepsilon} = \omega n / c$$

$$c = 1/\sqrt{\mu_0\varepsilon_0}$$

$$n = \sqrt{\frac{\mu\varepsilon}{\mu_0\varepsilon_0}}$$