9. Semiconductors

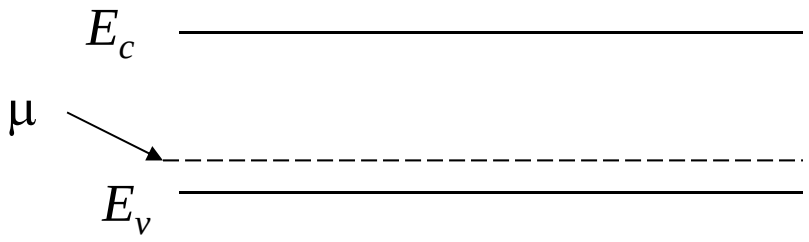
Oct 31, 2019

pn junction

under normal operation conditions

p-type

$N_A > N_D \qquad p = N_A - N_D$

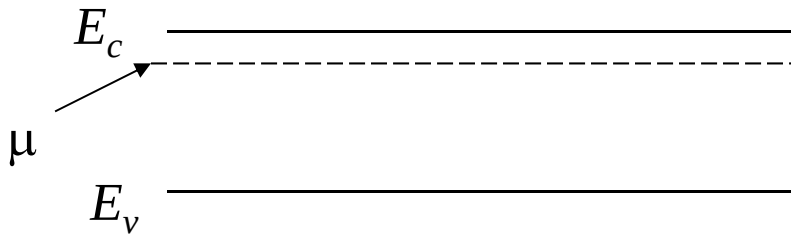


$$n = \frac{n_i^2}{p} = \frac{n_i^2}{N_A - N_D}$$

$$\mu = E_v + k_B T \ln\left(\frac{N_v}{N_A - N_D}\right)$$

n-type

$N_D > N_A \qquad n = N_D - N_A$

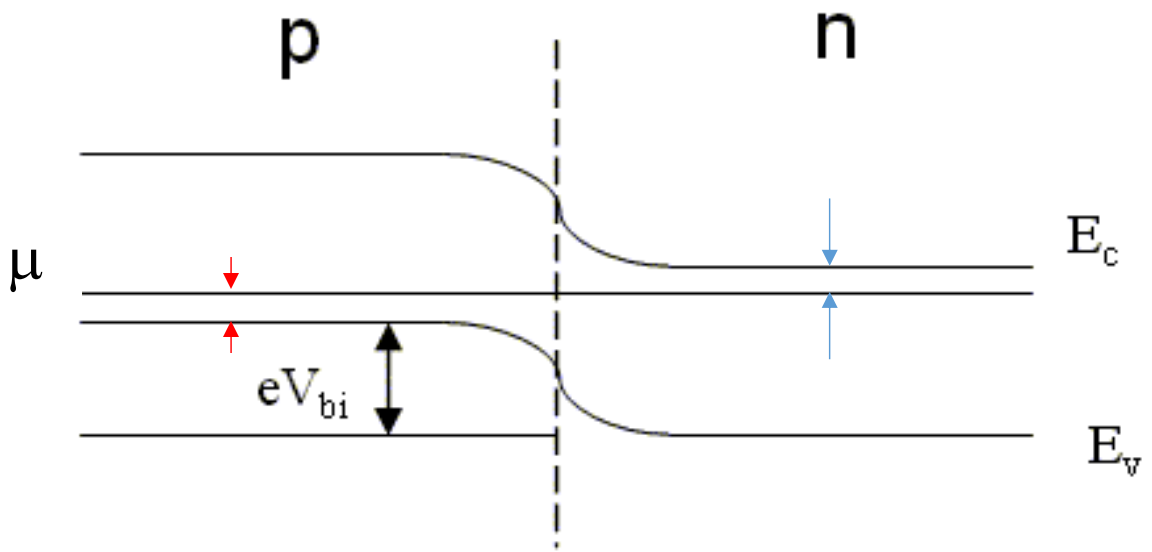


$$p = \frac{n_i^2}{n} = \frac{n_i^2}{N_D - N_A}$$

$$\mu = E_c - k_B T \ln\left(\frac{N_c}{N_D - N_A}\right)$$

Semiconductor devices Kittel p. 503 - 512

V_{bi} built-in voltage



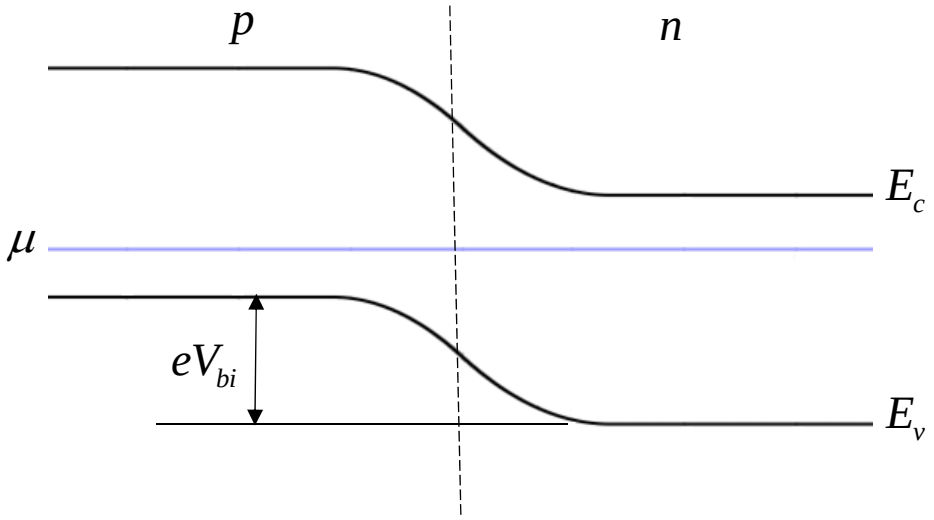
law of mass action

$$n_i^2 = N_c N_v \exp\left(\frac{-E_g}{k_B T}\right)$$

$$eV_{bi} = E_g - k_B T \ln\left(\frac{N_c}{N_D}\right) - k_B T \ln\left(\frac{N_v}{N_A}\right)$$

$$eV_{bi} = E_g - k_B T \ln\left(\frac{N_c N_v}{N_D N_A}\right) = k_B T \ln\left(\frac{N_D N_A}{n_i^2}\right)$$

p and n profiles



$V_{bi} \sim 1$ V

$W \sim 1$ μm

$E_{max} \sim 10^4$ V/cm

$$p = N_v \exp\left(\frac{E_v - \mu}{k_B T}\right)$$

$$n = N_c \exp\left(\frac{\mu - E_c}{k_B T}\right)$$

The electric field pushes the electrons towards the n-region and the holes towards the p-region.

Diffusion sends electrons towards the p-region and holes towards the n-region.

Abrupt pn junctions in the depletion approximation

In an abrupt pn junction, the doping changes abruptly from p to n. It is common to solve for the band bending, the local electric field, the carrier concentration profiles, and the local conductivity in the depletion approximation. In this approximation it is assumed that there is a depletion width W around the transition from p to n where the charge carrier densities are negligible. Outside the depletion width the charge carrier densities are equal to the doping densities so that the semiconductor is electrically neutral outside the depletion width. Using this approximation it is possible to calculate the important properties of the pn junction.

N_A = 1E15 1/cm³ N_D = 1E15 1/cm³ E_g = 1.166-4.73E-4*T*T/(T+636) eV

$N_v(300)$ = 9.84E18 1/cm³ $N_c(300)$ = 2.78E19 1/cm³ ϵ_r = 12 T = 300 K

μ_p = 480 cm²/V s μ_n = 1350 cm²/V s τ_p = 1E-10 s τ_n = 1E-10 s

V = -0.5 V

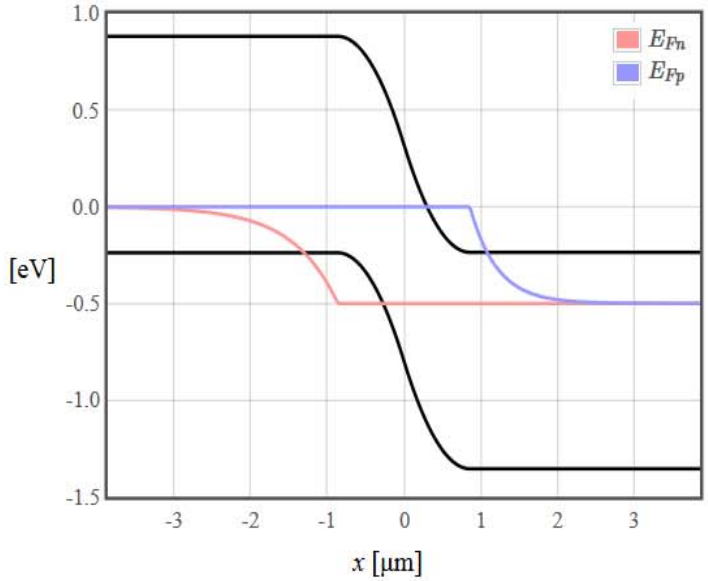
V

Submit

$E_g = 1.12$ eV $W = 1.72$ µm $x_p = -0.861$ µm $x_n = 0.861$ µm $V_{bi} = 0.618$ V $C_j = 6.17$ nF/cm²

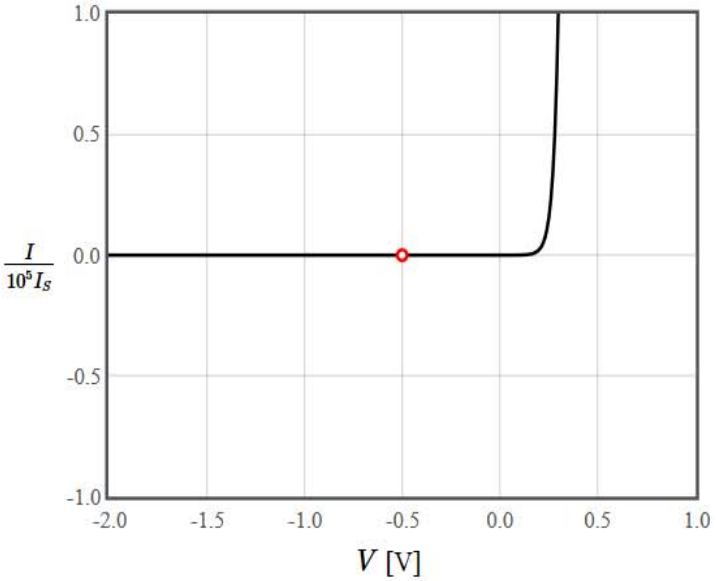
$D_p = 12.4$ cm²/s $D_n = 34.9$ cm²/s $L_p = 0.352$ µm $L_n = 0.591$ µm

Band diagram



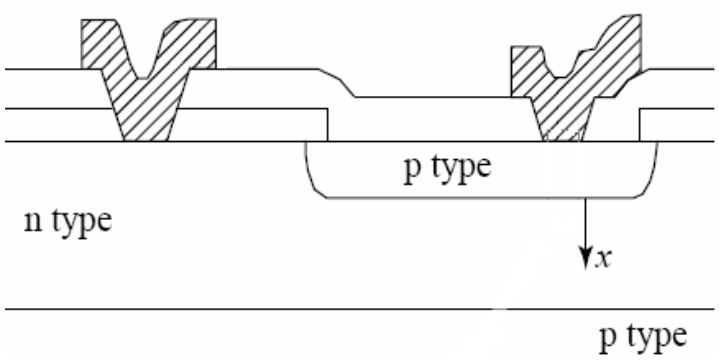
Charge density

Current-Voltage Characteristics

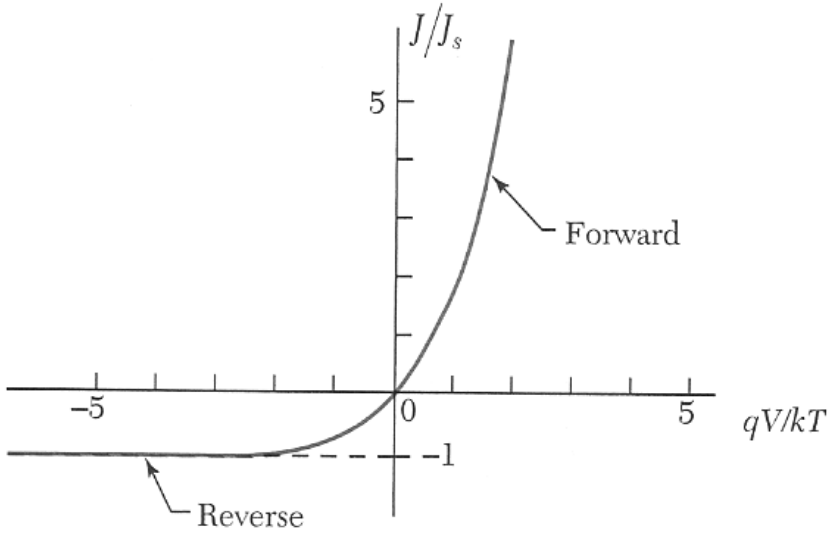


Electric field

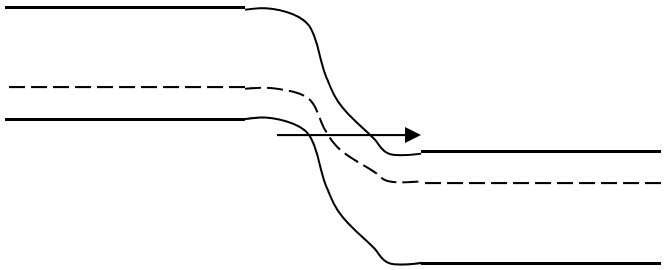
Diode



$$I = I_s\left(\exp\left(\frac{eV}{k_BT}\right)-1\right)$$

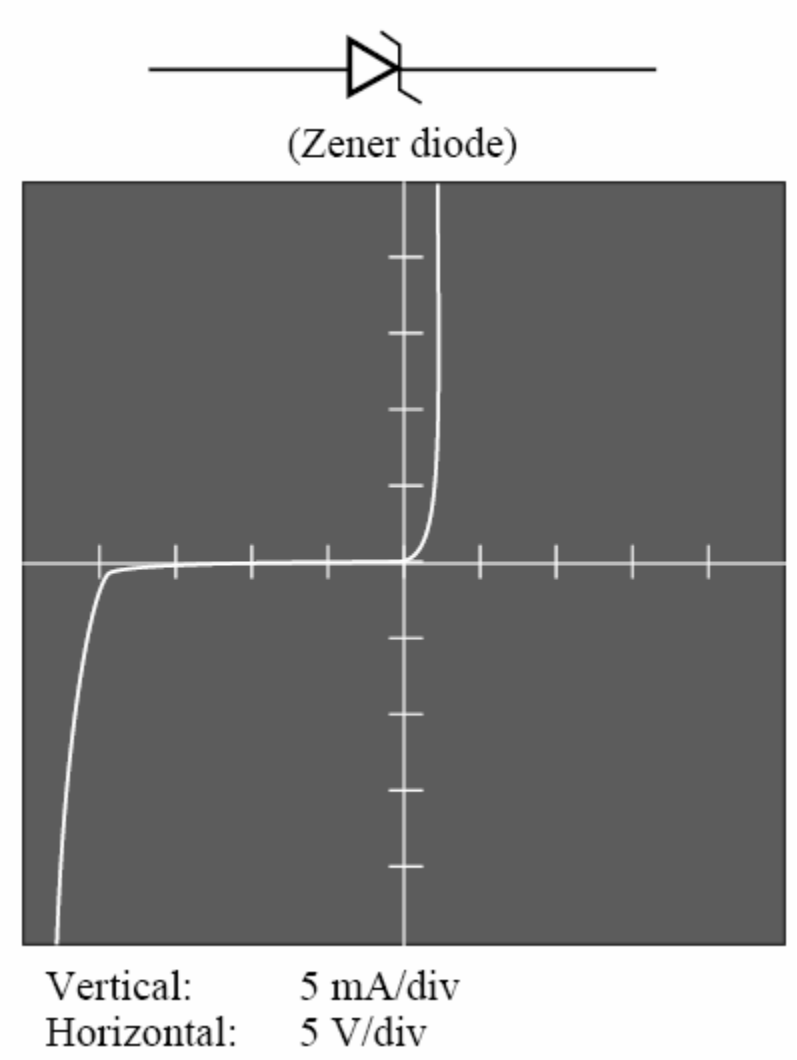


Zener tunneling

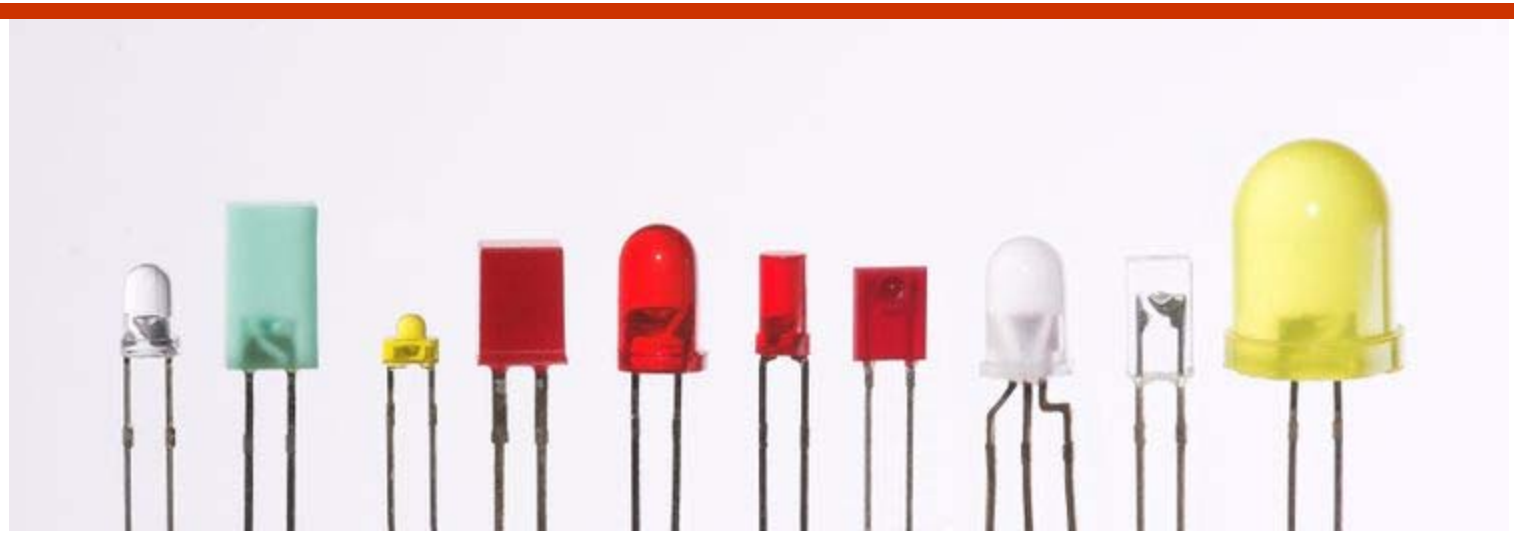


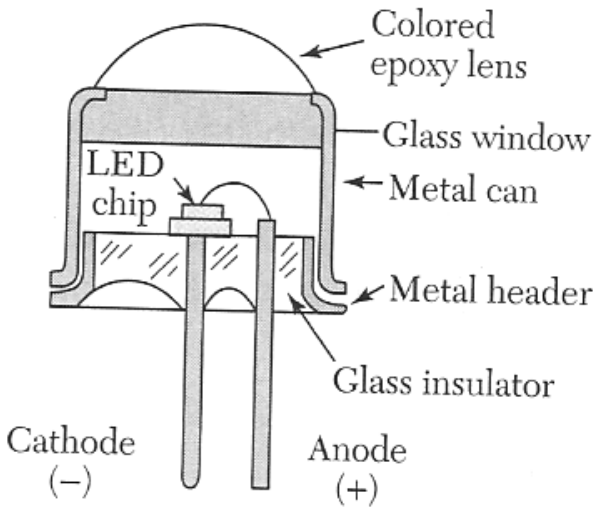
Electrons tunnel from valence band to conduction band

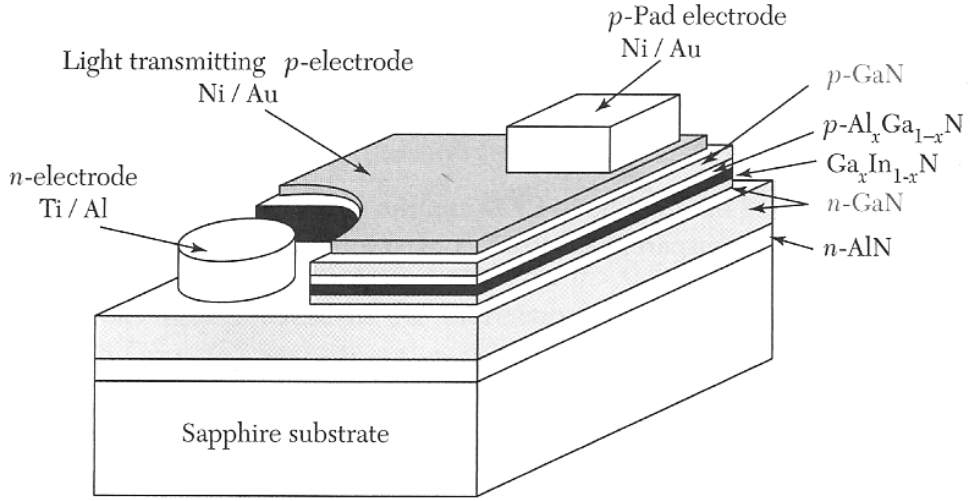
Occurs at high doping



Light emitting diodes

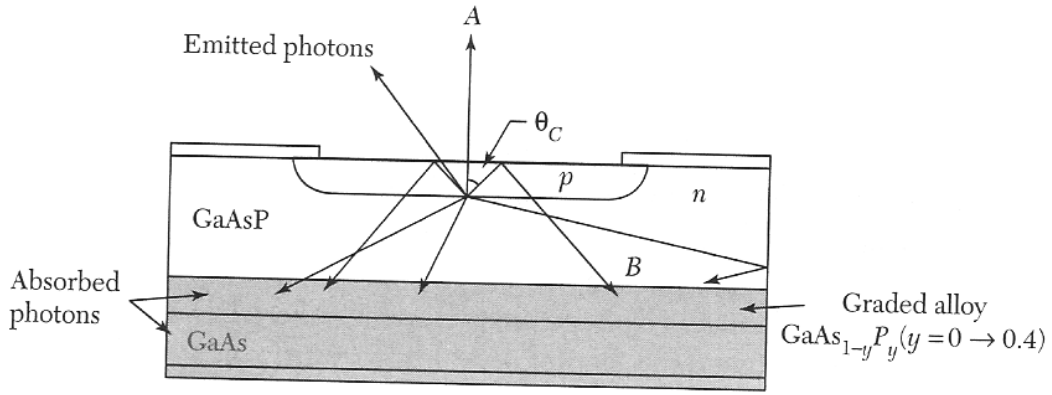




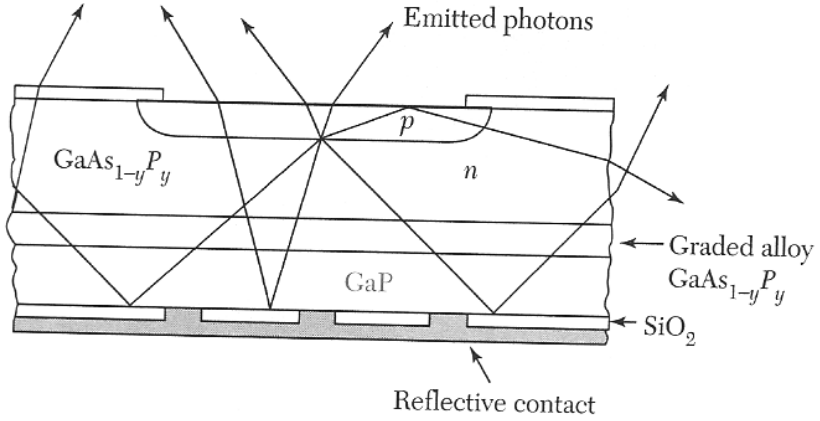


Solid state lighting is efficient.

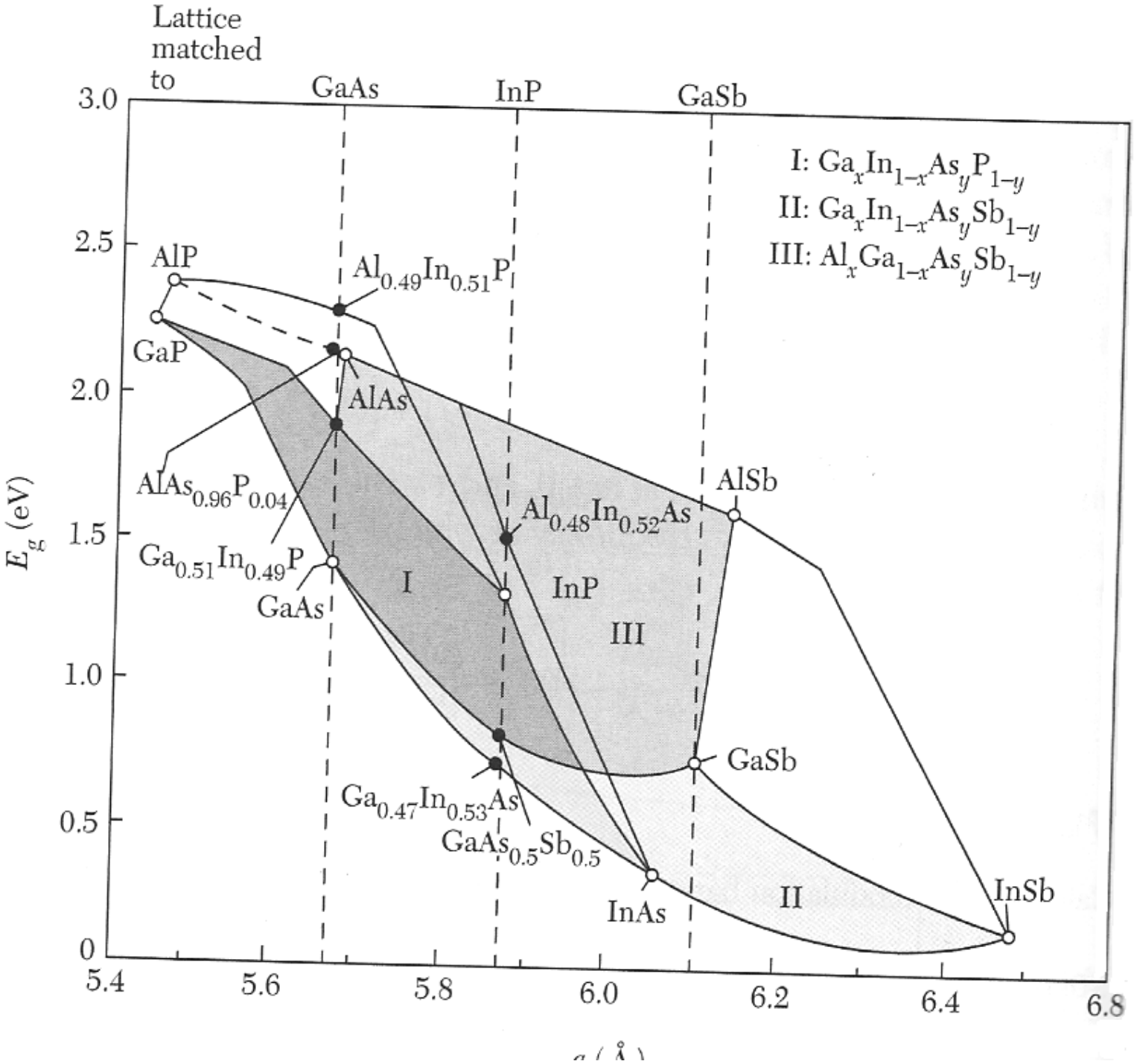
Light emitting diodes



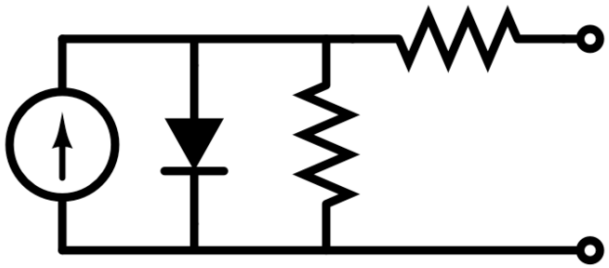
absorption
reflection
total internal reflection



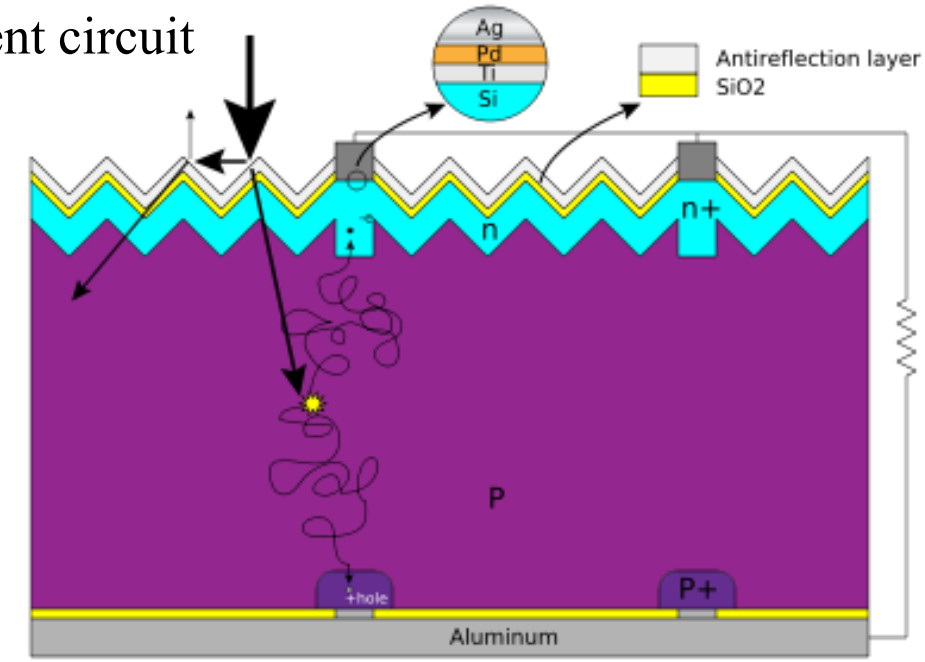
Electrons and holes are injected into the depletion region by forward biasing the junction. The electrons fall in the holes. For direct bandgap semiconductors, photons are emitted. For indirect bandgap semiconductors, phonons are emitted.

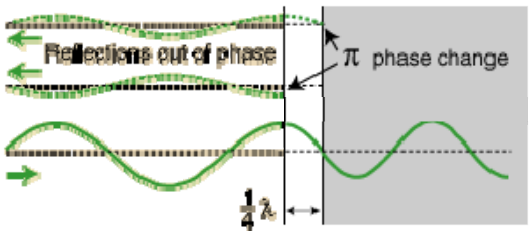

Lattice matched to
GaAs
InP
GaSb
I: $Ga_xIn_{1-x}As_yP_{1-y}$
II: $Ga_xIn_{1-x}As_ySb_{1-y}$
III: $Al_xGa_{1-x}As_ySb_{1-y}$
AlP
$Al_{0.49}In_{0.51}P$
GaP
AlAs
$AlAs_{0.96}P_{0.04}$
$Al_{0.48}In_{0.52}As$
AlSb
$Ga_{0.51}In_{0.49}P$
GaAs
I
InP
III
GaSb
$Ga_{0.47}In_{0.53}As$
$GaAs_{0.5}Sb_{0.5}$
InAs
II
InSb
E_g (eV)
3.0
2.5
2.0
1.5
1.0
0.5
0
5.4
5.6
5.8
6.0
6.2
6.4
6.8

Solar cell

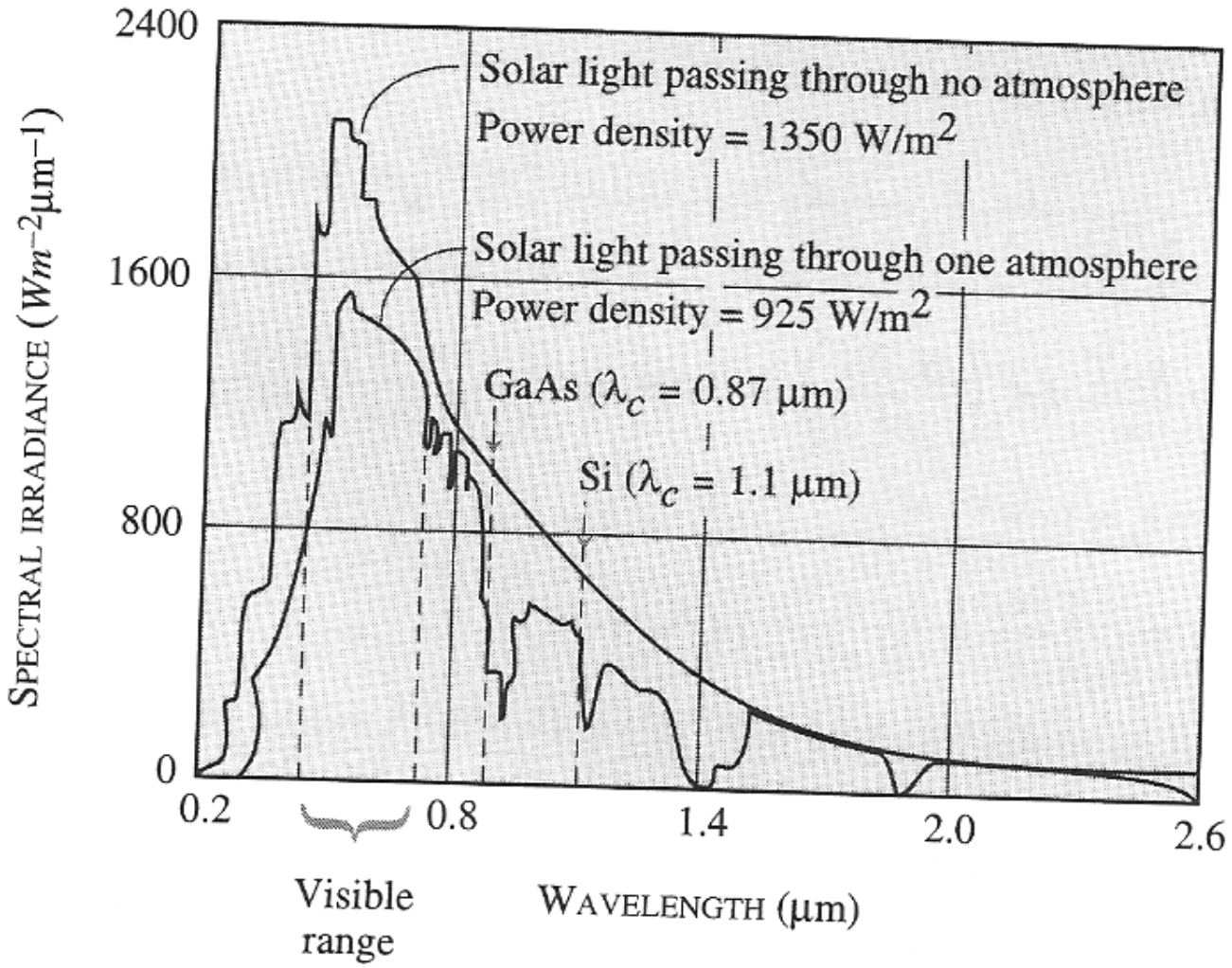


Equivalent circuit



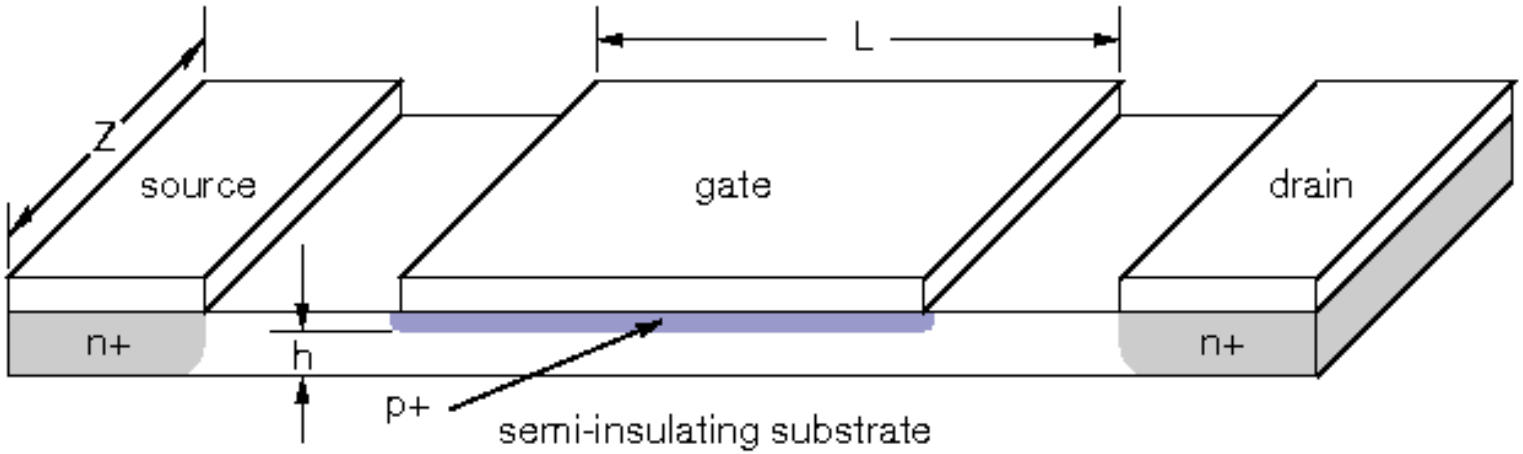


Solar spectrum



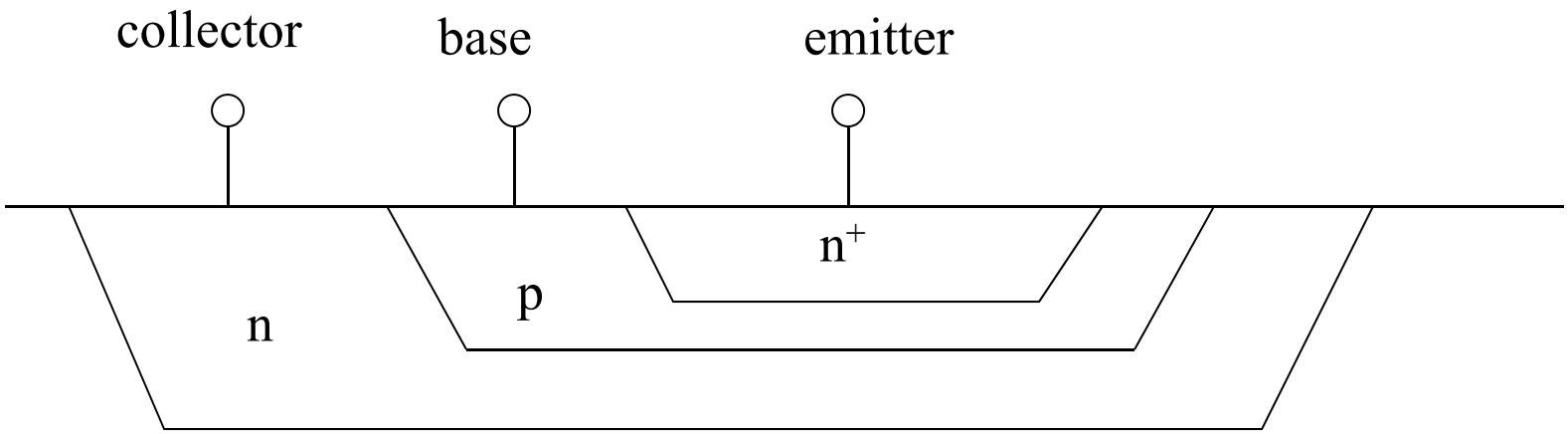
JFETs

Junction Field Effect Transistors



low noise

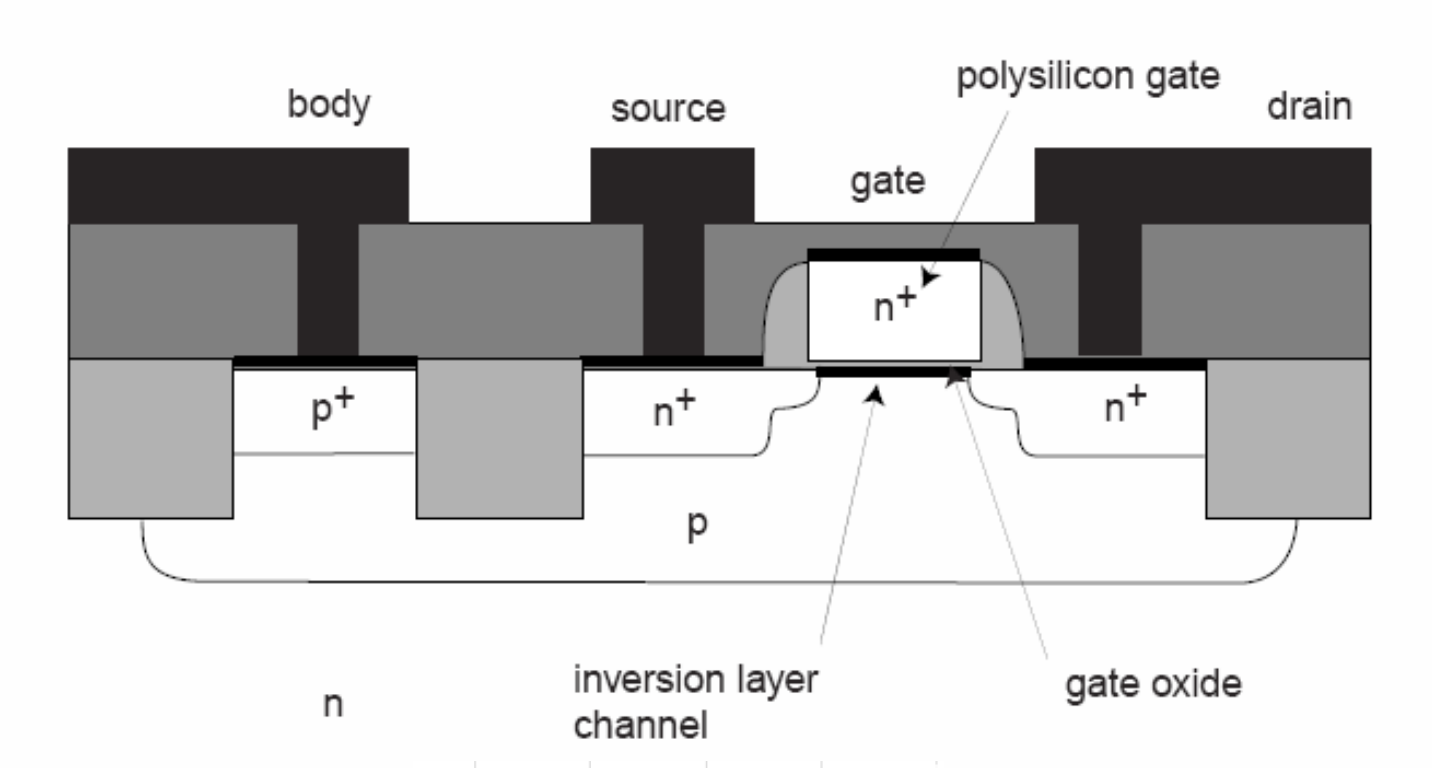
Bipolar transistor

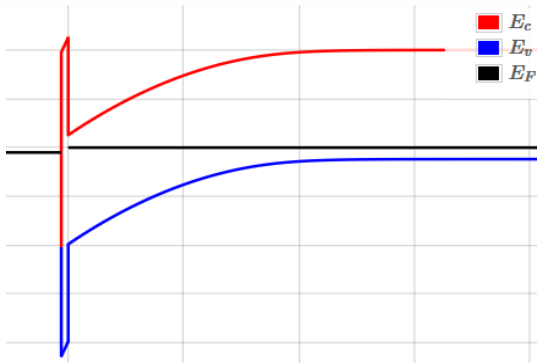


lightly doped p substrate

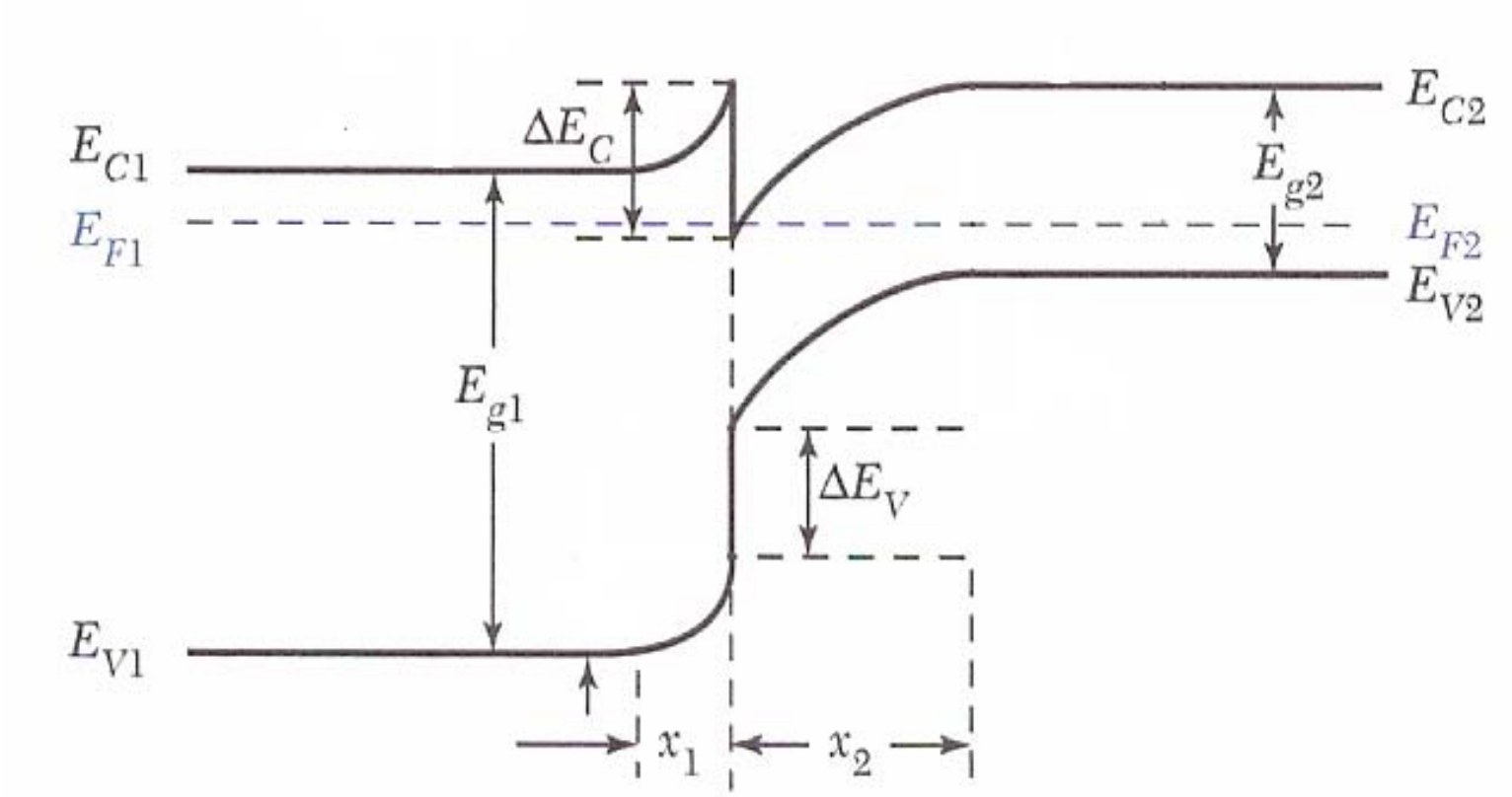
MOSFETs

Metal-oxide semiconductor field effect transistors





Heterojunctions



Quantum hall effect
Quantized conductance
HBTs
HEMTs

HEMT High electron mobility transistor