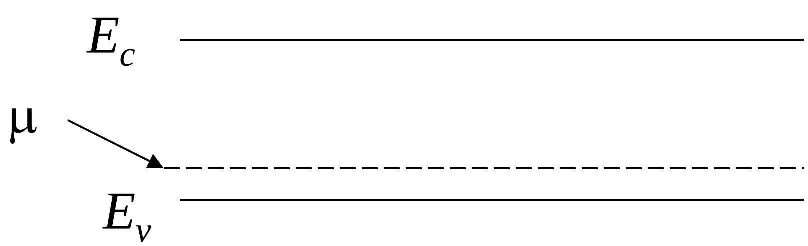
Semiconductor Devices

pn junction

under normal operation conditions

p-type

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

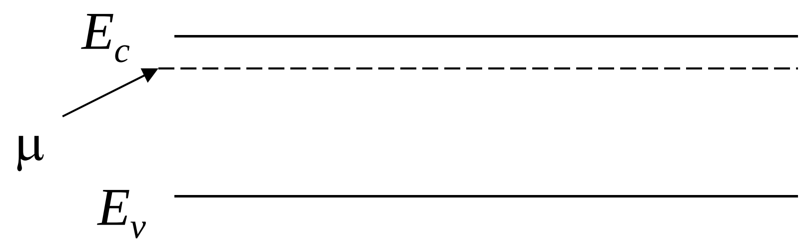


$$n = \frac{n_i^2}{p} = \frac{n_i^2}{N_A - N_D}$$

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

n-type

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

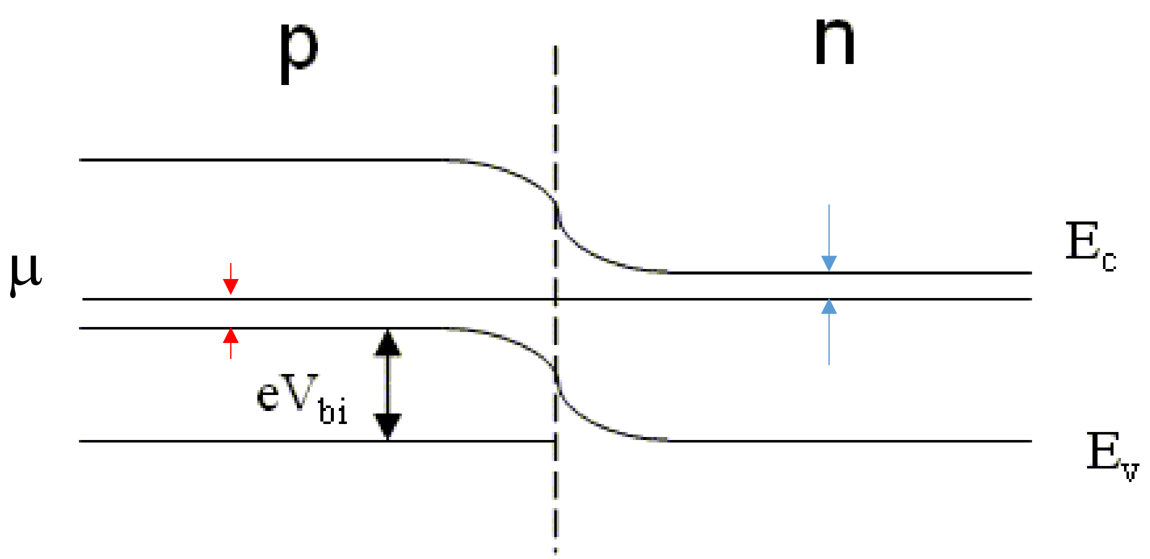


$$p = \frac{n_i^2}{n} = \frac{n_i^2}{N_D - N_A}$$

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

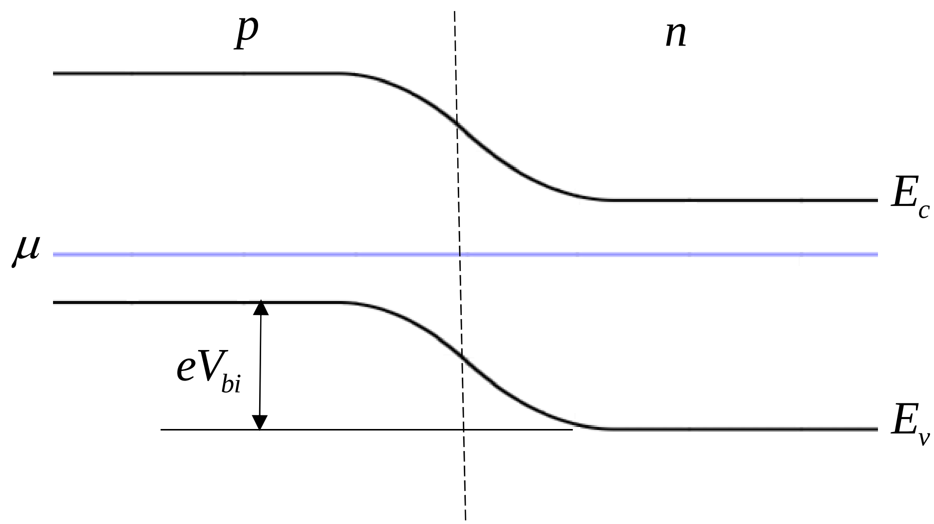
Semiconductor devices   Kittel p. 503 - 512

V_{bi} built-in voltage



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

p and n profiles



$V_{bi} \sim 1$ V

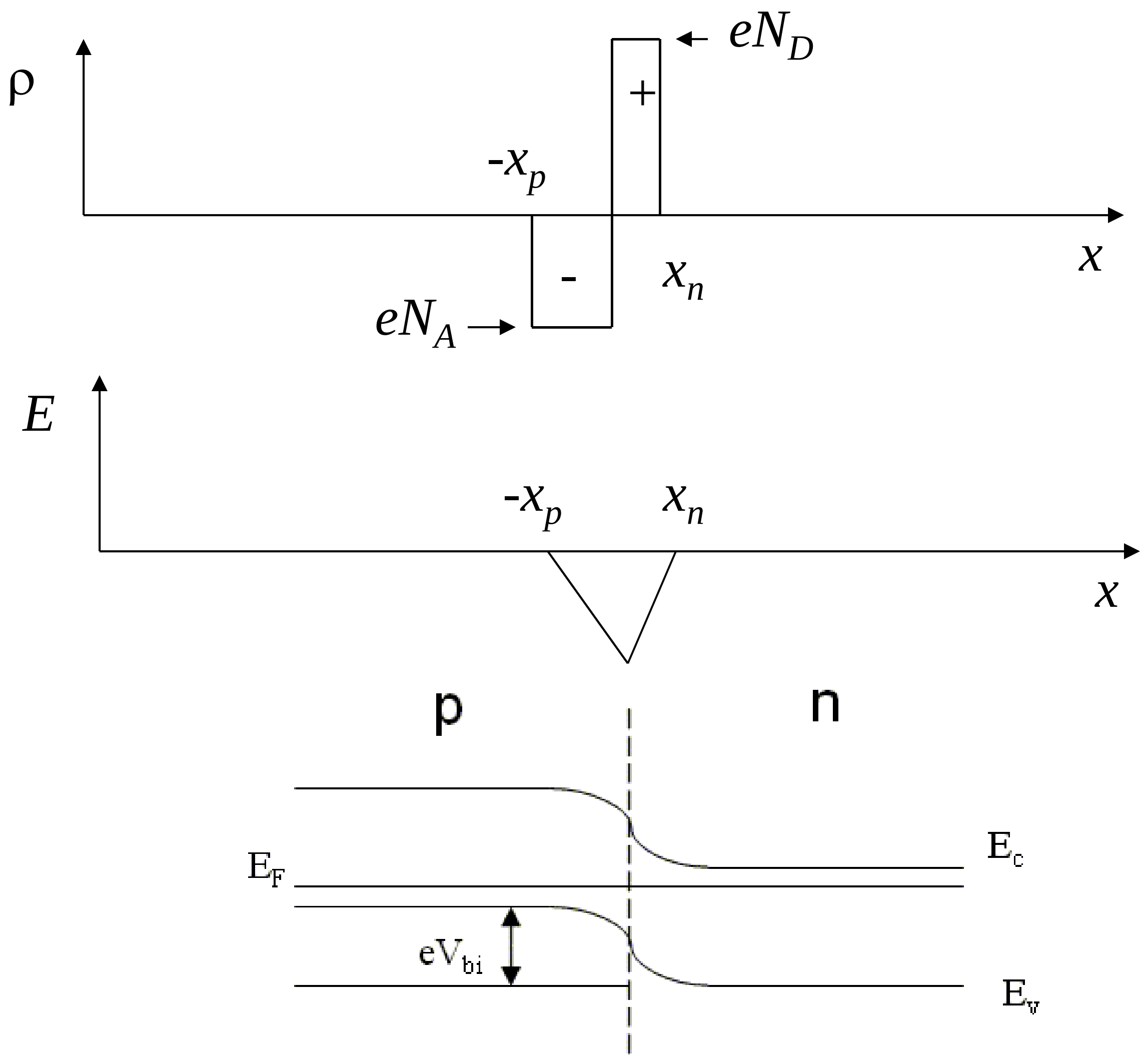
$W \sim 1$ μm

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

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

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

depletion approximation



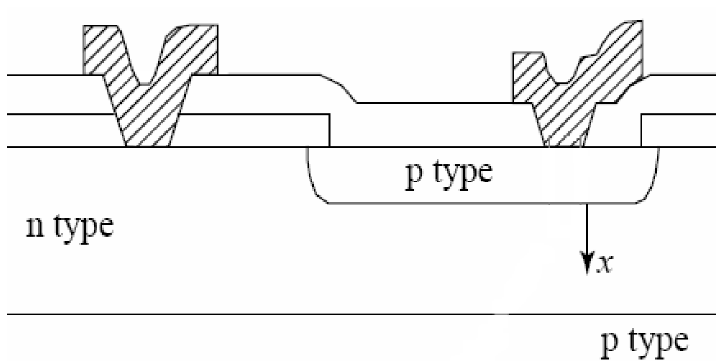
$$E = -\frac{eN_A}{\varepsilon}\left(x + x_p\right) \qquad -x_p > x > 0$$

$$E = \frac{eN_D}{\varepsilon}\left(x - x_n\right) \qquad 0 > x > x_n$$

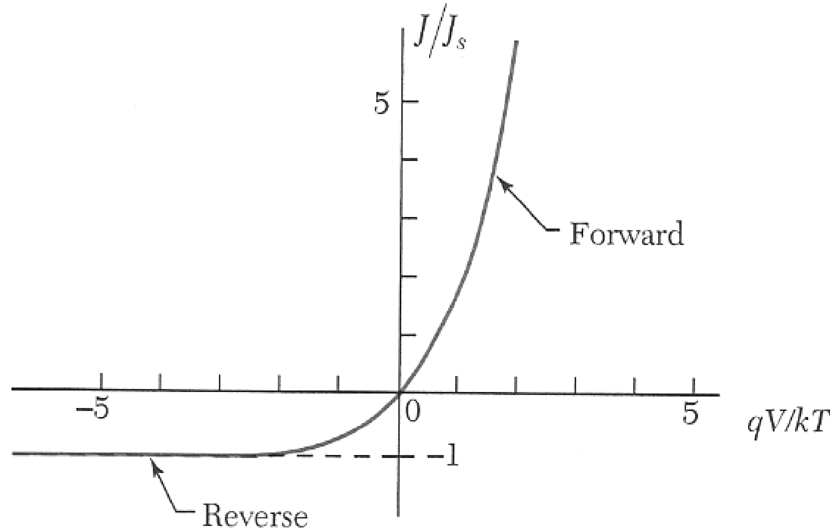
$$V = \frac{eN_A}{\varepsilon}\left(\frac{x^2}{2} + xx_p\right) \qquad -x_p > x > 0$$

$$V = \frac{-eN_D}{\varepsilon}\left(\frac{x^2}{2} - xx_n\right) \qquad 0 > x > x_n$$

Diode



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



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 $\epsilon_r =$ 12 $T =$ 300 K

$\mu_p =$ 480 cm²/V s $\mu_n =$ 1350 cm²/V s $\tau_p =$ 1E-10 s $\tau_n =$ 1E-10 s

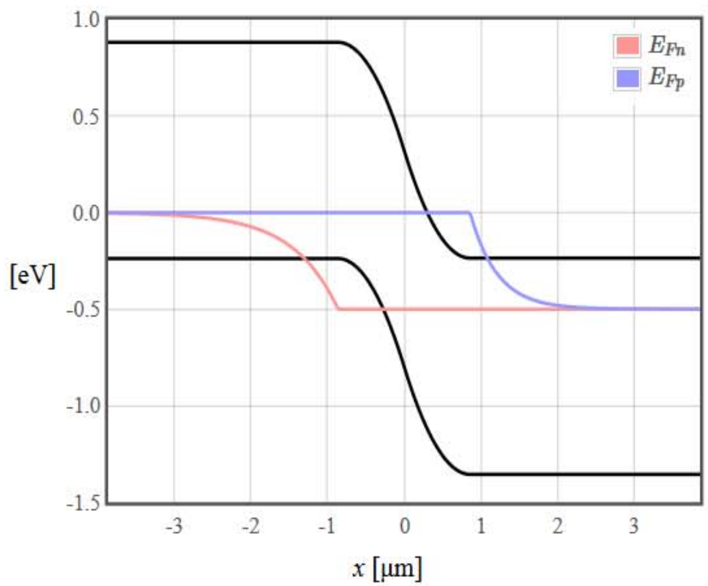
$V =$ -0.5 V Submit

V

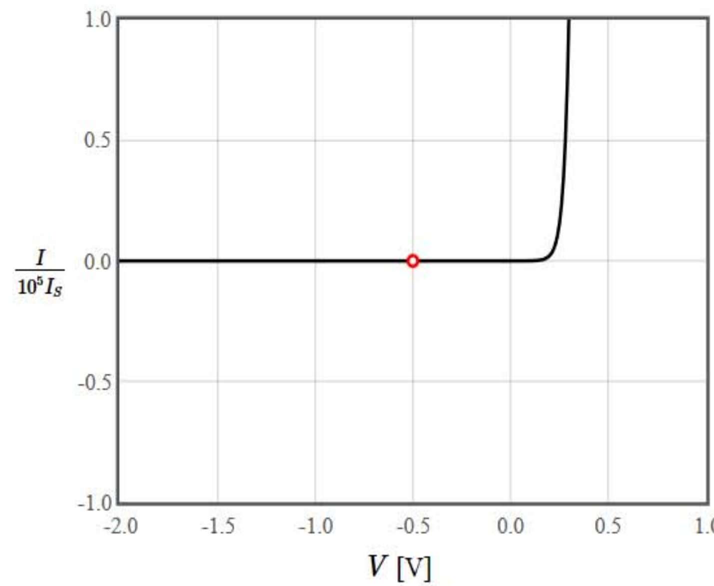
$E_g = 1.12$ eV $W = 1.72$ µm $x_p = -0.861$ µm $x_n = 0.861$ µm $V_{bi} = 0.618$ V $C_j = 6.17$ nF/cm²

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

Band diagram



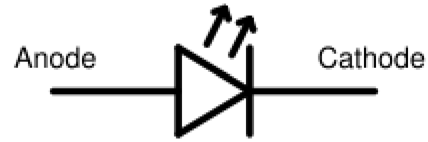
Current-Voltage Characteristics

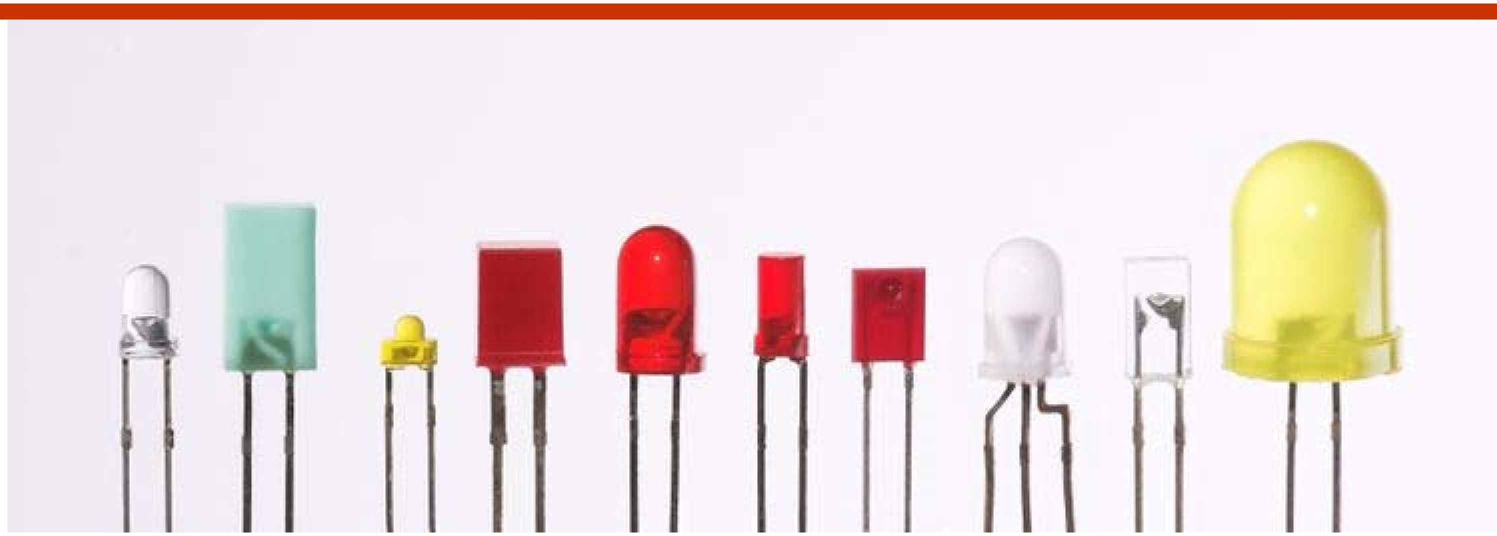


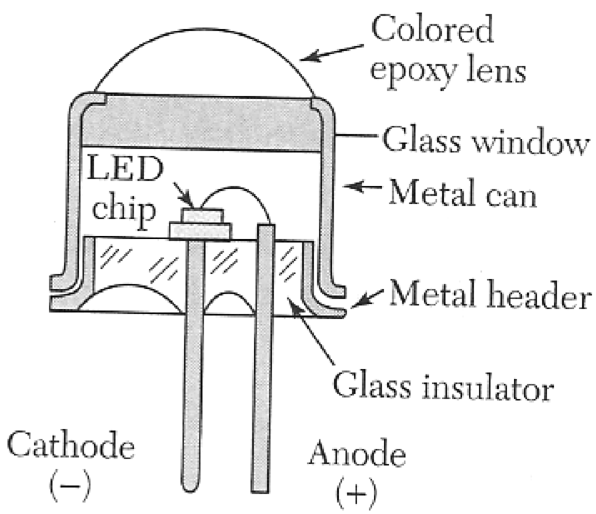
Charge density

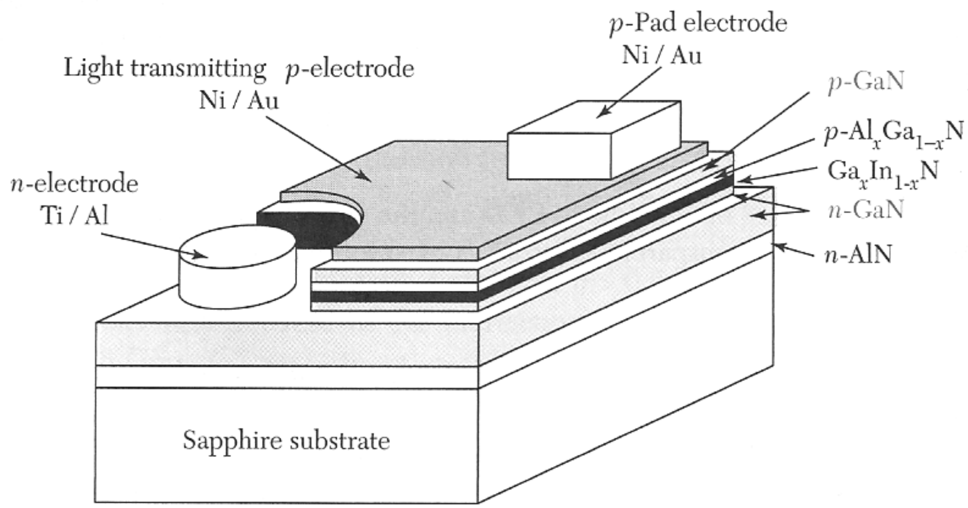
Electric field

Light emitting diodes



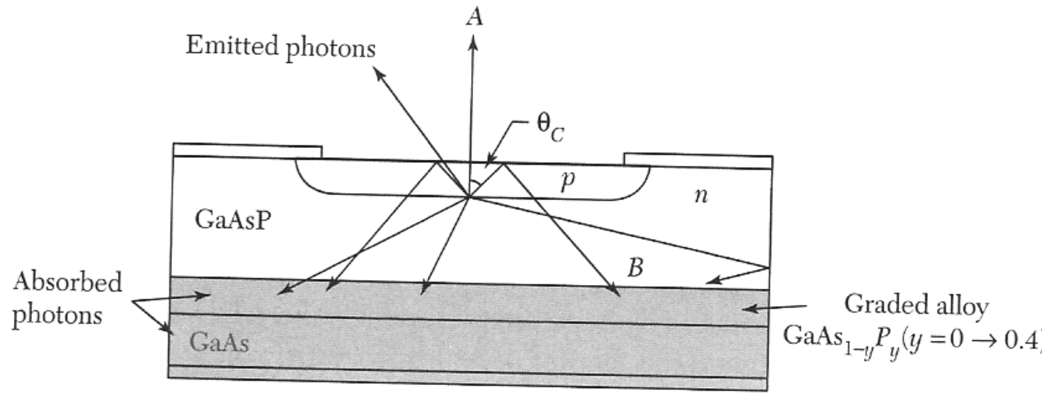




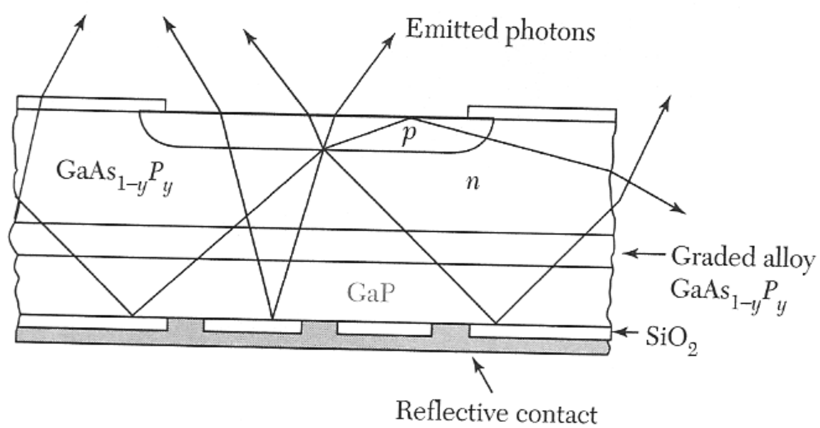


Solid state lighting is efficient.

Light emitting diodes

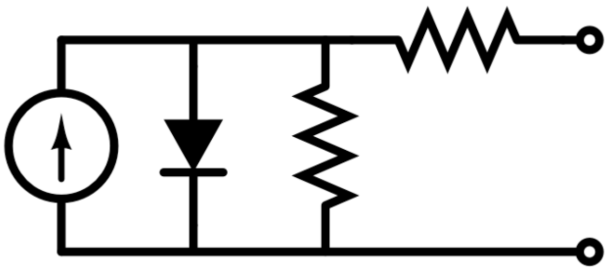


absorption
reflection
total internal reflection

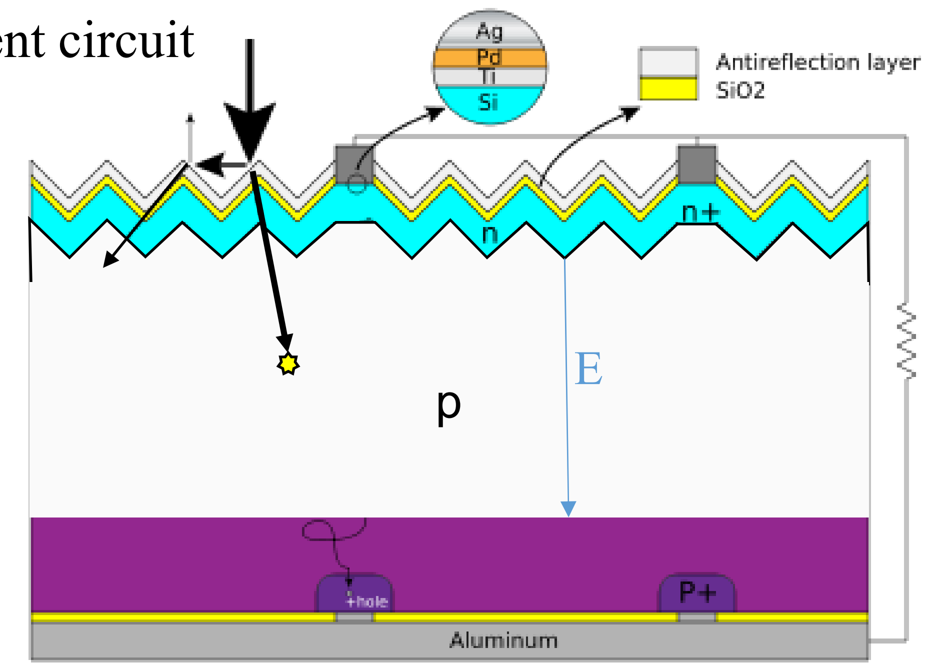


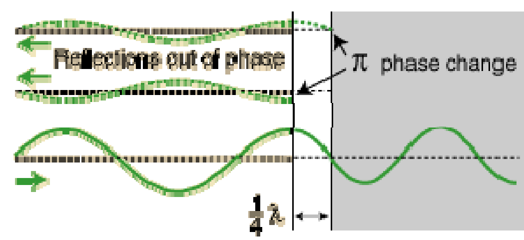
Electrons and holes are injected into the depletion region by forward biasing the junction. The electrons fall in the holes. For direct bandgap semiconductors, photons are emitted. For indirect bandgap semiconductors, phonons are emitted.

Solar cell



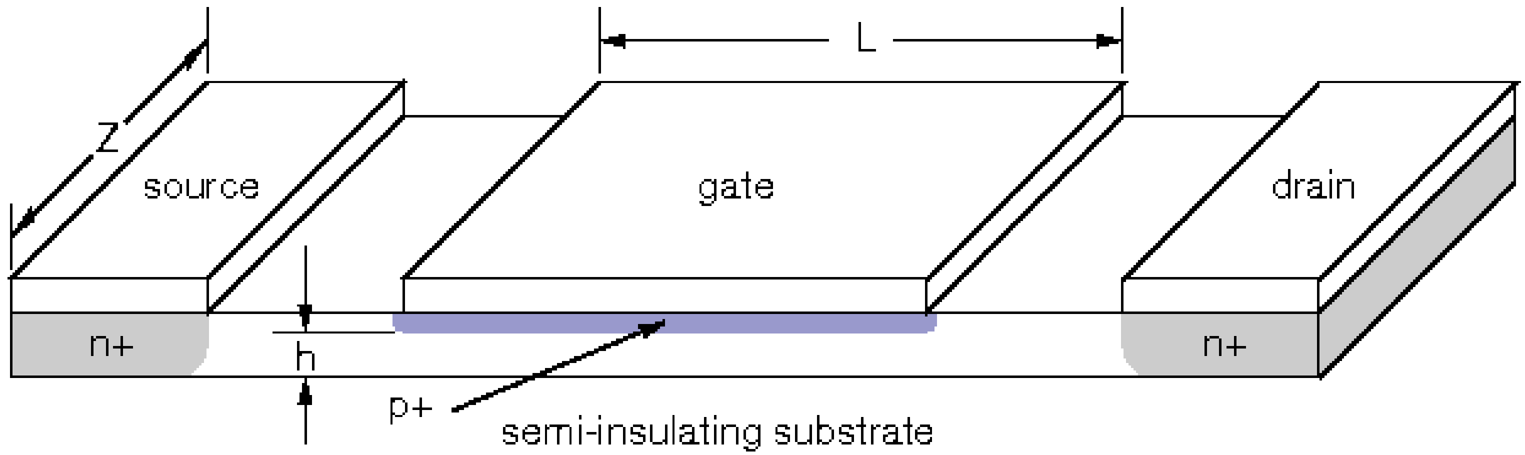
Equivalent circuit





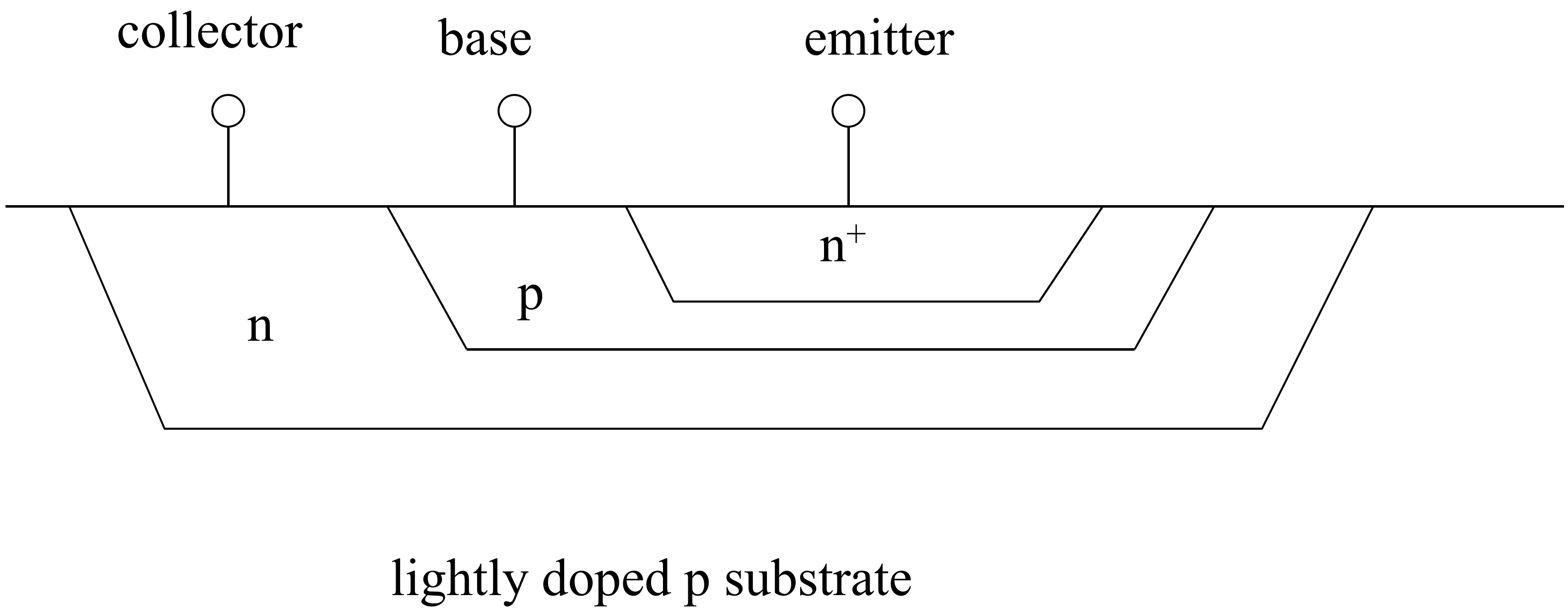
JFETs

Junction Field Effect Transistors



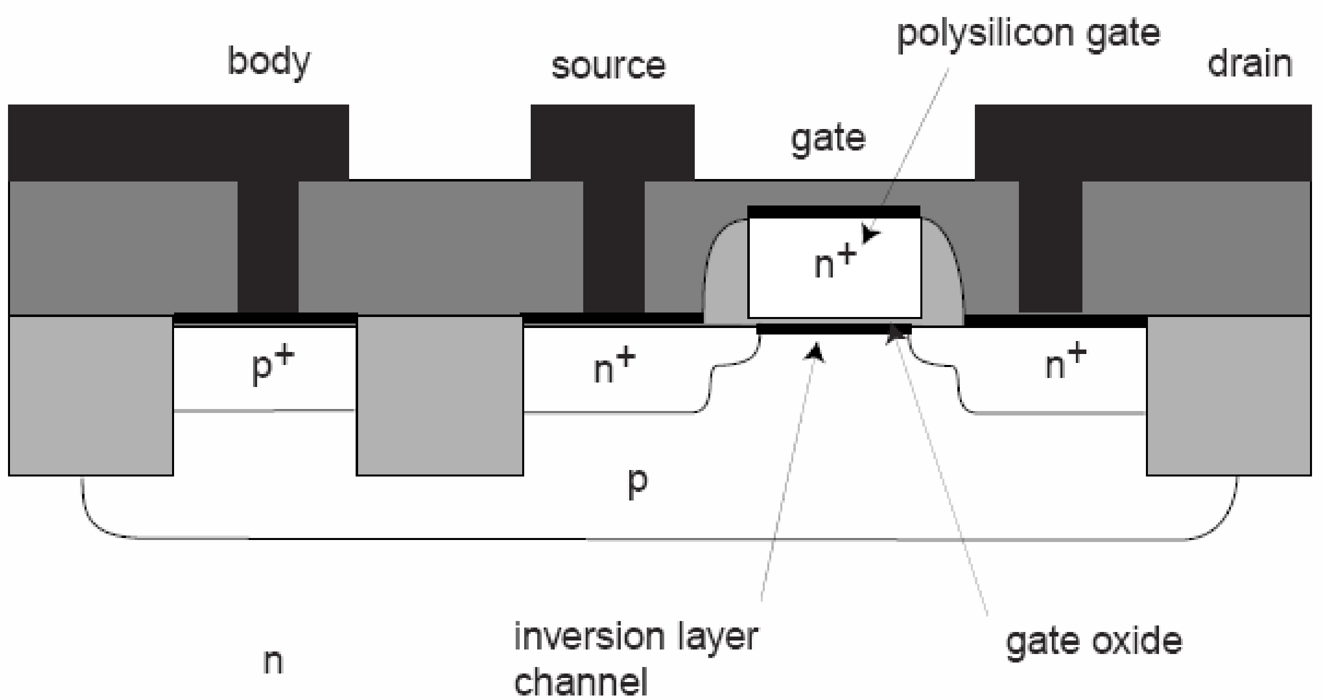
low noise

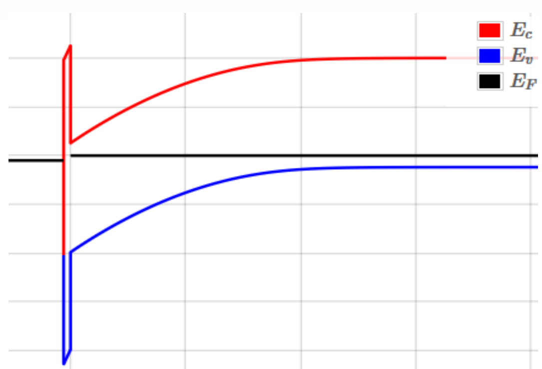
Bipolar transistor



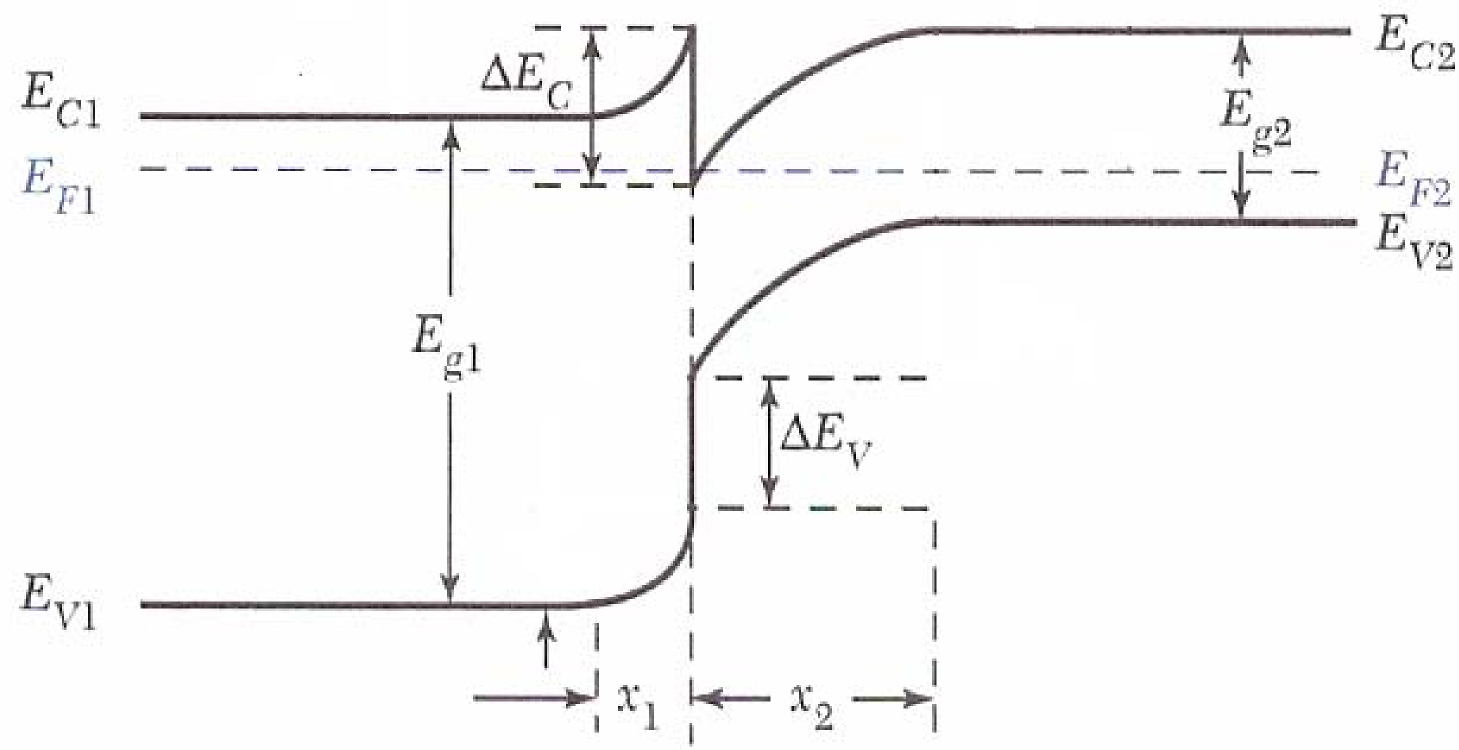
MOSFETs

Metal-oxide semiconductor field effect transistors





Heterojunctions



Quantum hall effect
Quantized conductance
HBTs
HEMTs

HEMT High electron mobility transistor

HBT Hetero junction bipolar transistor