# Lecture 20: Processes in Semiconductors

## Electrons and holes in semiconductors

Semiconductor with **band gap** $E_g = E_C - E_V$ and chemical potential μ has

electron density $n = n_C \exp(-(E_C - \mu)/kT)$, (20.1)
hole density $p = n_V \exp(-(\mu - E_V)/kT)$.

A **hole** is an electron vacancy in the valence band and has charge +e

In equilibrium:
μ constant
np = constant. This constant depends on $E_g$ and T, and is called $n_i^2$

**Doping** changes μ and the n/p ratio:
n-type doping: $N_D$ donor impurities. $\Rightarrow n = N_D$. $p = n_i^2 / N_D$
n >> p, therefore μ moves up (towards the conduction band)
p-type doping: $N_A$ acceptor impurities. $\Rightarrow p = N_A$. $n = n_i^2 / N_A$
p >> n, therefore μ moves down (towards the valence band)

## Electron processes in semiconductors

Charge generation rate $G = \int \alpha\, b\, dE$ [ $m^{-3}\ s^{-1}$]
(b = local spectral photon flux density)

Charge recombination rate :
*e.g.* in p-doped material $R = (n - n_0) / t_n \approx n / t_n$ [ $m^{-3}\ s^{-1}$]

Charge transport:
Diffusion current density (electrons) $J_n = e D_n\, dn/dx$ ($D_n$ = e diffusion coefficient)
Drift current density (electrons) $J_n = e\, m_n F\, n$ ($m_n$ = e mobility)
For holes, there are analogous terms: Diffusion: $J_p = -e D_p\, dp/dx$ Drift: $J_p = e\, m_p F\, n$

*Diffusion* is the most important transport process in a photovoltaic cell.

## Chemical potential due to radiation

Photogeneration increases the electron density and hole density, so that the electron and hole populations no longer obey eqn 20.1 with the same μ. We define new, separate μ values for electrons and holes, so that

electron density $n = n_C \exp(-(E_C - \mu_n)/kT)$,
hole density $p = n_V \exp(-(\mu_p - E_V)/kT)$.

$\Delta\mu = \mu_n - \mu_p$ is the chemical potential available for electrical work.

## Continuity equation

Conserving particle flow in element of thickness dx,
for electrons: $(J_n(x+dx) - J_n(x)) = -e\,(G - R)\,dx$

Continuity equation:

$$\frac{1}{e}\frac{dJ_n}{dx} + G - R = 0$$