Modeling and simulation of semiconductors and semiconductor devices

Exercise 2

Implementation of the bulk semiconductor equations

builds on modules: 2,3,4,5

check out: Get ready for GNU Octave (exercise 1)

https://octave.sourceforge.io/secs1d/overview.html

Implementation of the bulk semiconductor equations

check out:

Explanation of quasi-Fermi levels (TUBE SS 2020)

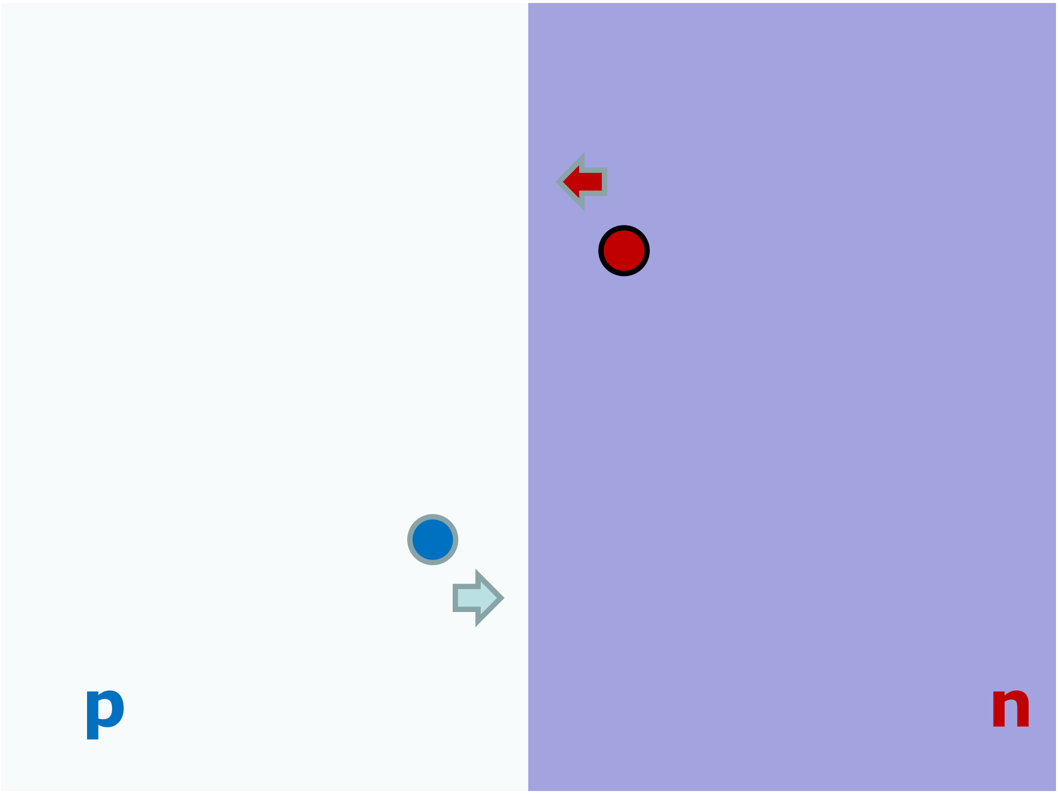
Your will …

1) .. learn to predict current densities across a pn junction for a given voltage in a self-consistent fashion

2) .. learn how device geometries, material properties, boundary conditions, and initial conditions are passed to a finite difference solver

3) .. alter the workflow of the simulation to mimic a particular experiment

pn junction
thermal equilibirium



no net current

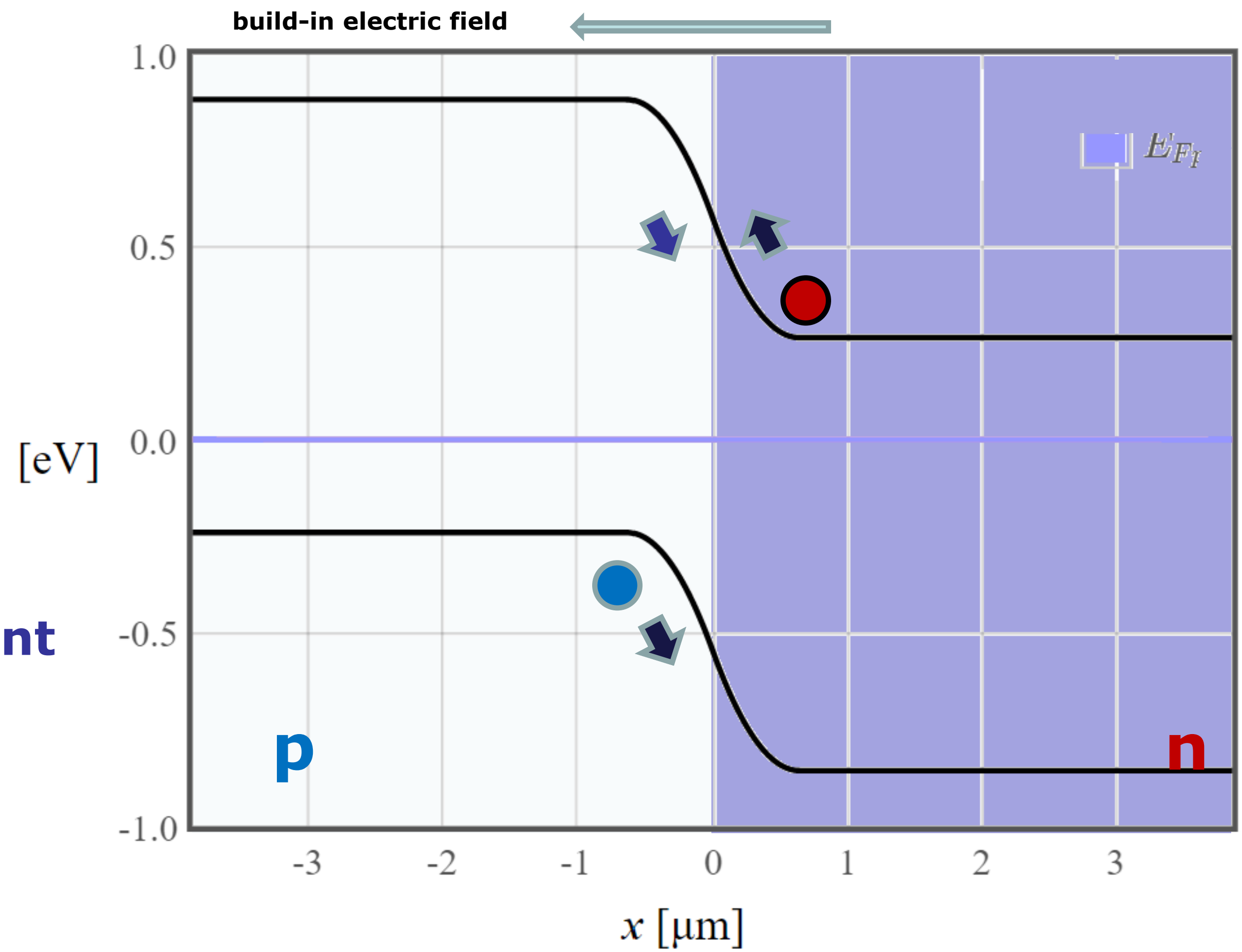
pn junction
thermal equilibirium

drift current

=

- diffusion current

no net current



pn junction

thermal equilibirium

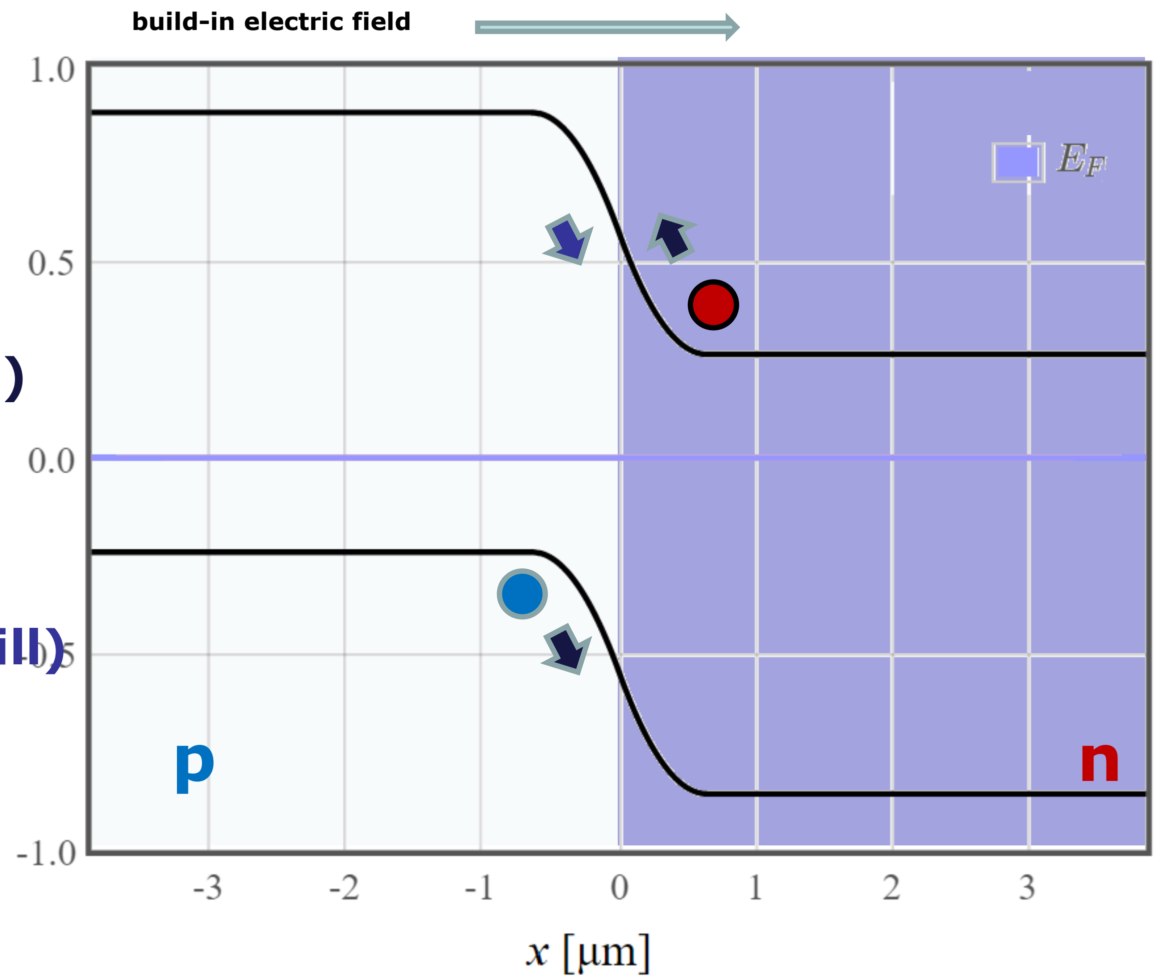
drift current (downhill)

motion without energy barrier

diffusion current (uphill)

motion against energy barrier

key to current control: alter balance



http://lampz.tugraz.at/~hadley/psd/L6/abrupt.html

pn junction
with voltage

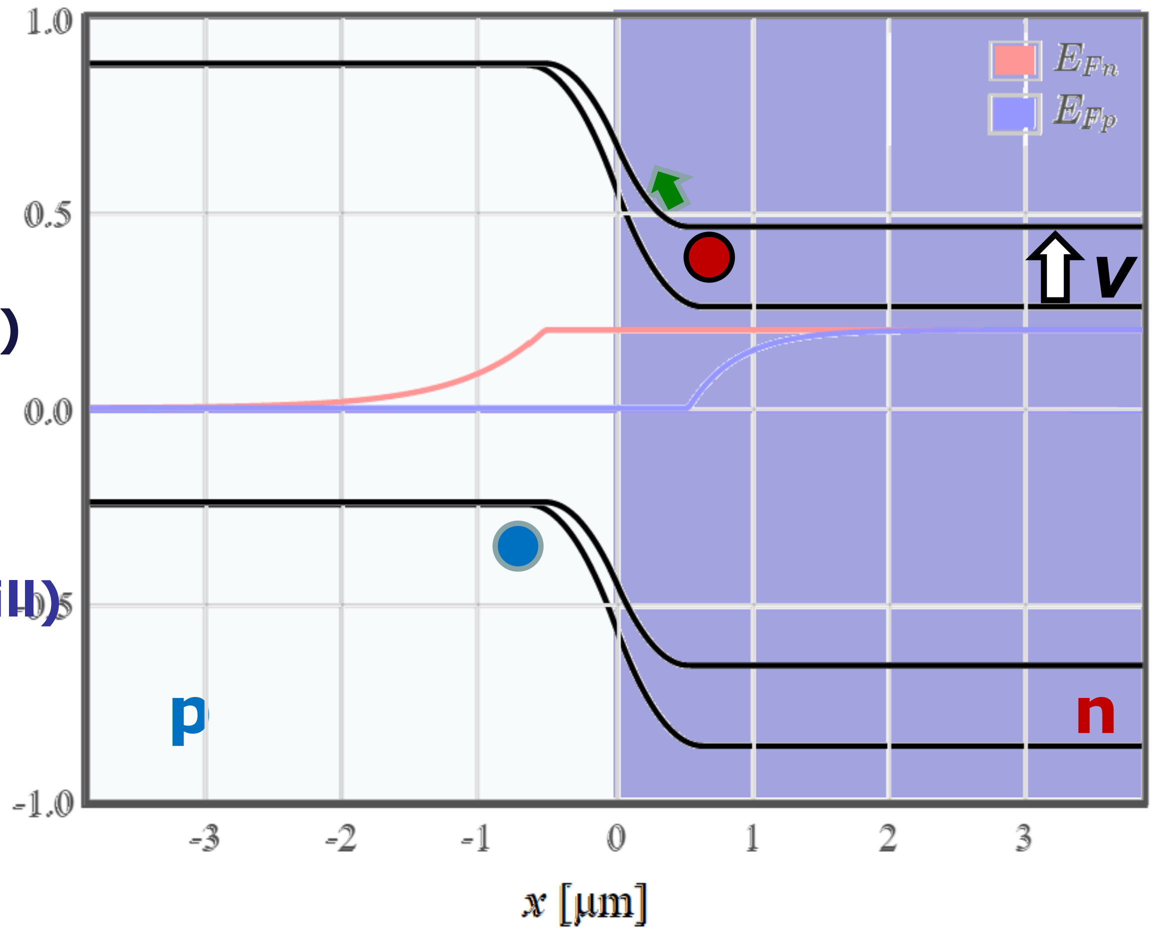
drift current (downhill)

motion without energy barrier

diffusion current (uphill)

barrier reduced: motion activated with bias or enlarged temperature

build-in electric field

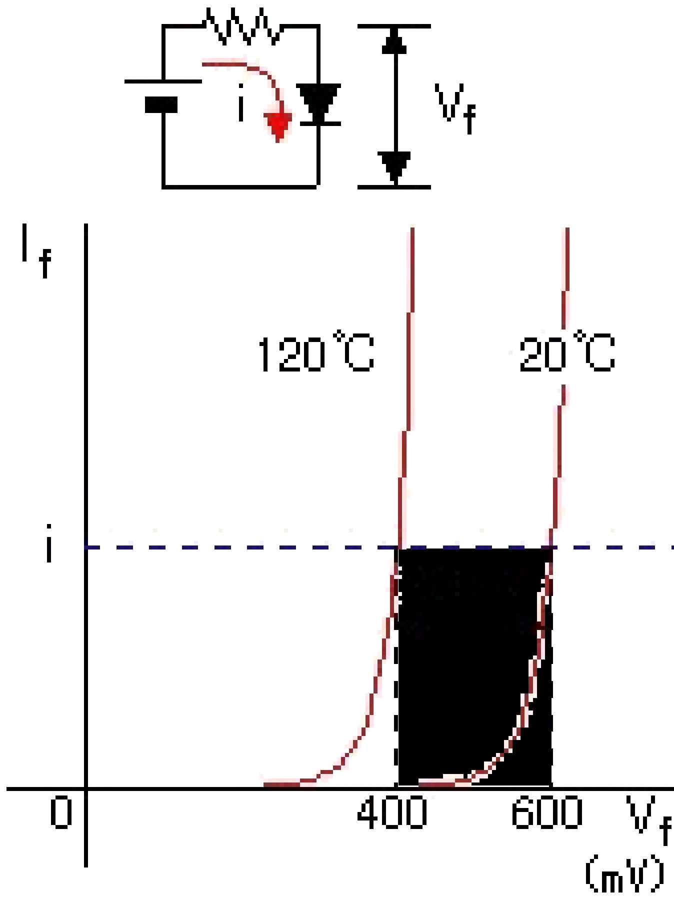


http://lampx.tugraz.at/~hadley/psd/L6/abrupt.html

pn-diode as a **thermometer**

voltage offset at reference current *i*

proportional to temperature



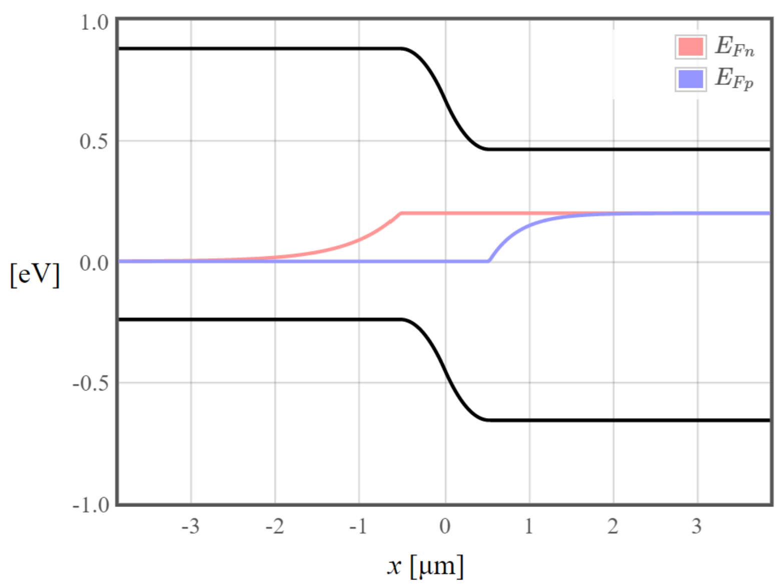
Si diode with predefined doping concentrations and geometry

simulation script

1) Get current density j – voltage V curves

for different charge carrier lifetimes

➢ **What shapes the j-V curves?**



Si diode with predefined doping concentrations and geometry

simulation script

2) Get current density j – voltage V curves

for different acceptor doping densities

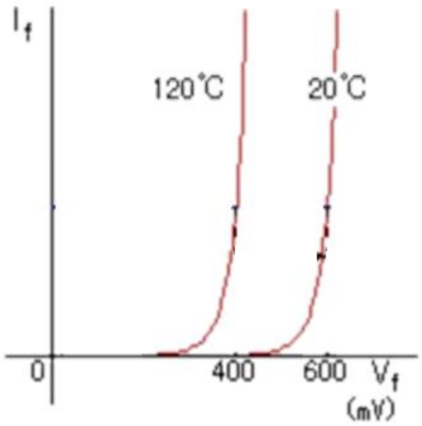
- **Which conditions are challenging for the solver?**

Si diode with predefined doping concentrations and geometry

simulation script

3) Get current density – voltage curves for different temperatures for fixed doping densities

➢ **Which regions of the j-V curves are reasonably ideal?**



Get voltage-temperature curve for preselected reference currents

$$\frac{\partial n}{\partial t} = \frac{1}{e}\frac{\partial \vec{j}_n}{\partial \vec{r}} + \boxed{G_n(I, \vec{r}, \vec{E}, T)} - \boxed{R(n, p)}$$

$$\frac{\partial p}{\partial t} = -\frac{1}{e}\frac{\partial \vec{j}_p}{\partial \vec{r}} + \boxed{G_p(I, \vec{r}, \vec{E}, T)} - \boxed{R(n, p)}$$

Steady state condition

$$0 = \frac{1}{e}\frac{\partial \vec{j}_n}{\partial \vec{r}} + \boxed{G_n(I, \vec{r}, \vec{E}, T)} - \boxed{R(n, p)}$$

$$0 = -\frac{1}{e}\frac{\partial \vec{j}_p}{\partial \vec{r}} + \boxed{G_p(I, \vec{r}, \vec{E}, T)} - \boxed{R(n, p)}$$

uses Slootboom variables

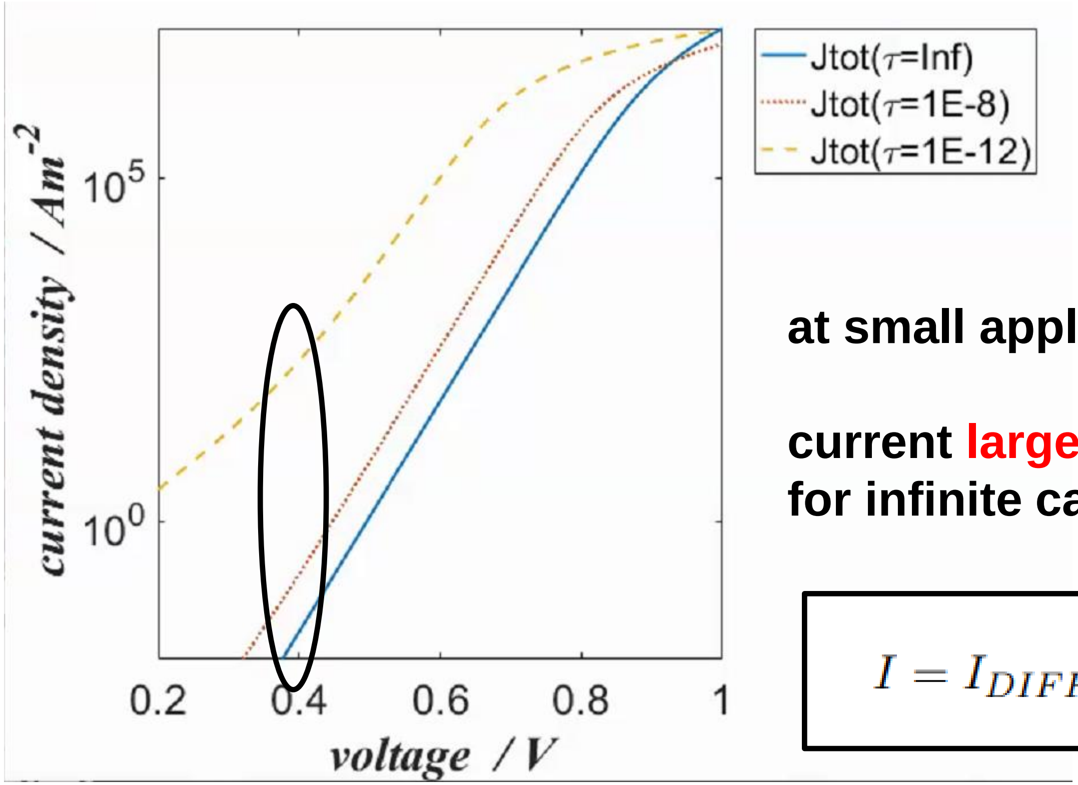
Assumes Boltzmann statistics:

Connects charge density with electrostatic potential

$$n = \eta e^{\frac{\psi}{k_B T}} = e^{\frac{\psi - \xi_p}{k_B T}}$$

quasi-Fermilevels

$$p = \rho e^{-\frac{\psi}{k_B T}} = e^{\frac{\xi_p - \psi}{k_B T}}$$



at small applied voltages:

current larger than expected for infinite carrier lifetimes

$$\boxed{I = I_{DIFF} + I_{R-G}}$$

additional current contribution: thermal carrier generation and recombination

forward bias: **carrier concentrations increase in the depletion region**
leads to the carrier recombination

model? Shockley Read Hall recombination

$$I_{R-G} = -2eA\int_{-x_p}^{x_n} \frac{\partial n}{\partial t}_{R-G} dx$$
$$= -2eA\int_{-x_p}^{x_n} \frac{n_i^2 - np}{\tau_p(n+n_T)+\tau_n(p+p_T)} dx$$

$$n_T = n_i e^{\frac{E_T - E_i}{k_b T}}$$
$$p_T = n_i e^{\frac{E_i - E_T}{k_b T}}$$

$$I_{R-G} = \frac{-2eAn_i^2}{\tau_p n_T + \tau_n p_T}\sqrt{\frac{2\epsilon_s\left(\phi_{bi}+V_R\right)}{eN}}\frac{1-e^{\frac{eV_A}{k_b T}}}{1+\frac{e(\phi_{bi}-V_A)}{k_b T}\frac{\sqrt{\tau_n\tau_p}}{2\tau_0}e^{\frac{eV_A}{2k_b T}}}$$

https://web.eecs.utk.edu/~azeumaul/courses/ee531/fall2019/lecturenotes/ECE531-Fall-19-Lecture-09-PN%20Junctions%20IV%20Characteristics%202.pdf