ECE 340 Review Session (Exam 2)

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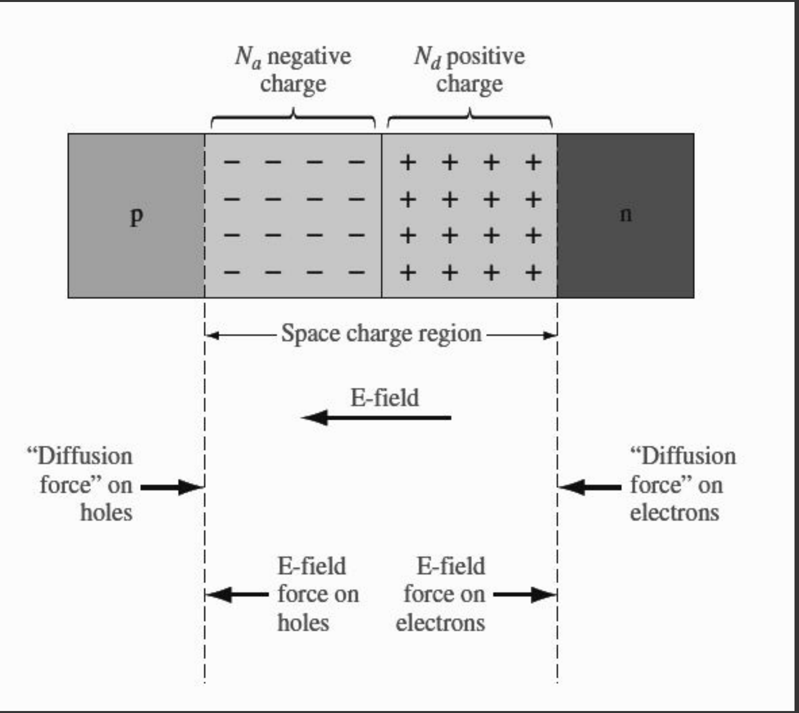
PN JUNCTION (EQUILIBRIUM)

- The combination of an n-type and p-type semiconductor.
- Majority carriers from each region begin to diffuse, leaving behind ionized donors and acceptors. These ionized dopants create an electric field.
- At equilibrium, the net current through the junction is zero.
- The drift current (caused by the electric field) and the diffusion current (movement of mobile carriers) cancel each other out.
- A built-in potential is created in the depletion region.



PN̄ JUNCTION (contd.)

- The fermi level is constant at equilibrium.
- The built-in potential is determined by the difference between the intrinsic fermi levels in the p and n junctions.
- Useful equations to know:

Built-in Potential:

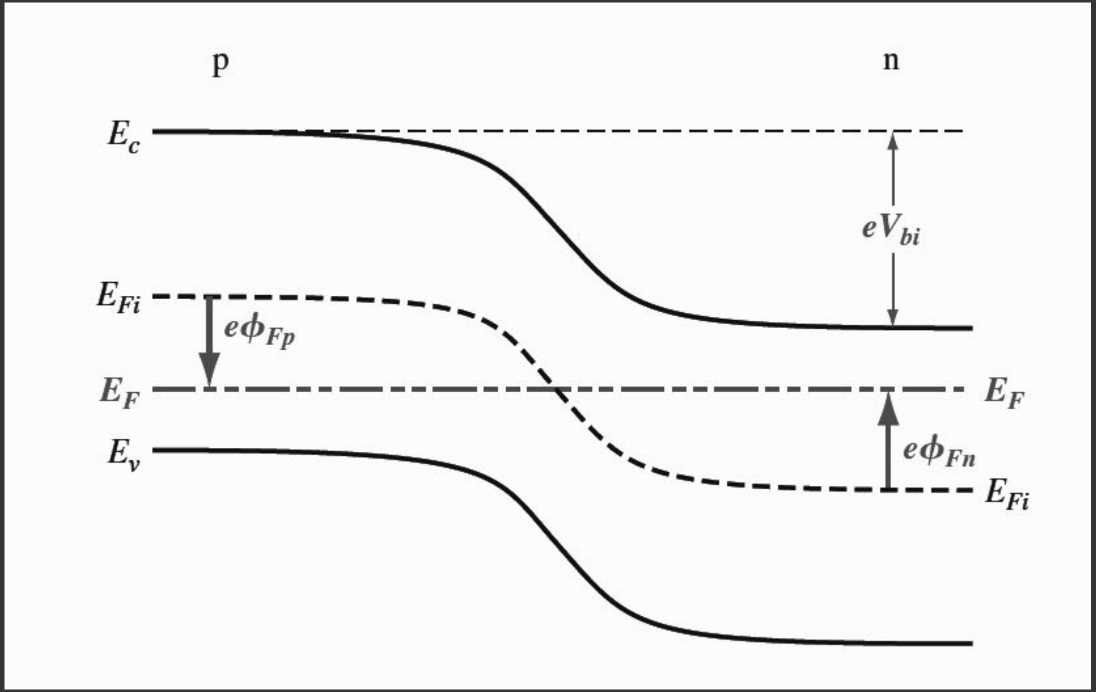
- $V = \frac{kT}{e} ln(\frac{N_a N_d}{ni^2})$

Depletion Width:

- $W = \sqrt{\frac{2\varepsilon V}{q}(\frac{1}{N_a} + \frac{1}{N_d})}$

Capacitance:

- $C = \frac{dQ}{dV} = \frac{\varepsilon A}{W}$



PN JUNCTION (Electrostatics)

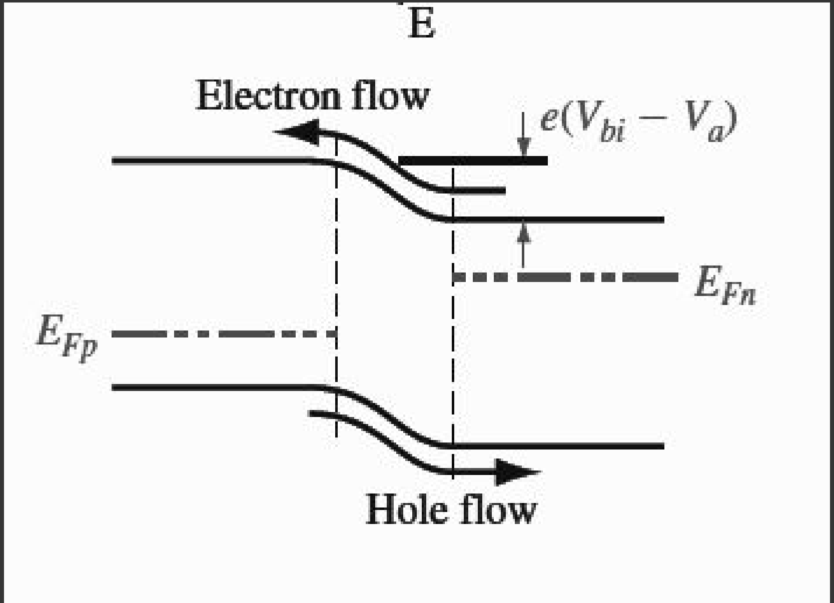
- For the purposes of this class, we are making an assumption that there is only charge in the depletion region provided by uncompensated dopants. There are no carriers providing charge in the depletion region. In addition, the semiconductor is neutral outside of the depletion region. This approximation is called the depletion approximation.
- Using this assumption we can provide an electrostatic profile of the PN Junction through Poisson's Equation:
  - $\frac{-d^2V(x)}{dx^2} = \frac{\rho(x)}{\epsilon} = \frac{dE(x)}{dx}$
  - $E(x) = \int \frac{q}{\varepsilon}(p - n + N_d - N_a)\,dx$
  - $V = -\int E(x)\,dx$

N^+N Junction

- Draw the charge density profile
- Draw the electric field profile
- Draw the voltage profile
- Fundamentally, how is the mechanism of carrier movement different than a PN junction?
- Draw a qualitative band diagram. Assuming Boltzmann approximation is a fine substitute for Fermi-Dirac Statistics, show the limitations in how you draw the Fermi levels.

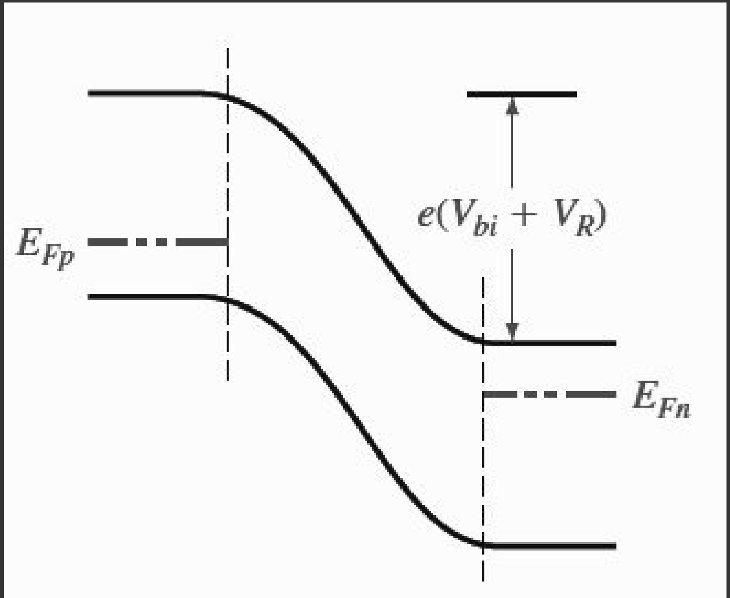
PN JUNCTION (Forward Bias)

- Apply a positive voltage to a PN Junction (positive is applied to the p-side).
- The potential barrier in the depletion region decreases, allowing for holes from the p-side to diffuse to the n-side (and vice versa).
- The junction is no longer at equilibrium. We have quasi-fermi levels.
- Fn is above Fp.
- Depletion Width decreases.
- Diffusion capacitance is prominent.



PN JUNCTION (Reverse Bias)

- Apply a negative voltage to a PN Junction (positive is applied to the n-side).
- The potential barrier in the depletion region increases, so majority of current is provided by the drift current of minority carriers. The drift current is relatively insensitive to the voltage applied because there are few minority carriers to be swept away.
- The junction is no longer at equilibrium.
- Fn is below Fp.
- Depletion Width increases.
- Junction capacitance is prominent.



PN JUNCTION (Reverse Bias)

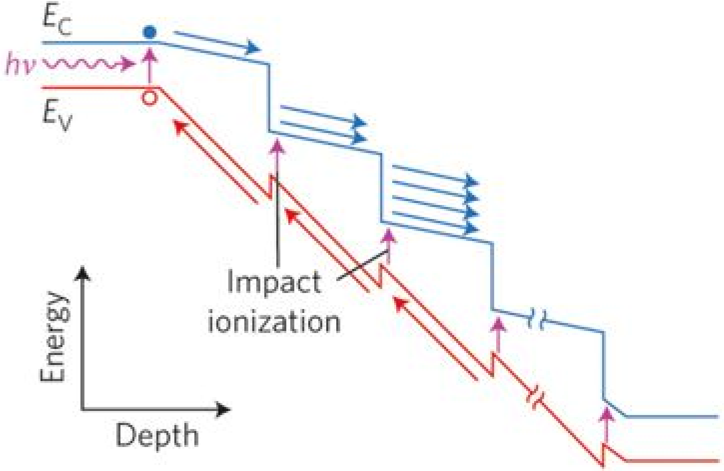
For a reverse biased PN junction there are two breakdown mechanisms:

- **Zener Breakdown:** When both sides of the junction are heavily doped such that the depletion width is small. Only a small reverse bias is needed to cause the n-side conduction band to fall below the p-side of the valence band. As of a result, electrons can tunnel through from the valence band of the p-side to the conduction band of the n-side. **High Doping, Low Voltages.**

- **Avalanche Breakdown:** At high reverse biases, the electric field within the depletion region will be large. As of a result, electrons and holes are accelerated and have high kinetic energies. These carriers impact the lattice and create electron-hole pairs (impact ionization). The newly created electrons and holes are also accelerated and can impact the lattice. Thus, the process creates an exponential increase in current. **Low doping, High Voltages**.

Breakdown

- If we increase the temperature of a PN junction under moderate reverse bias, what will happen to the magnitudes of the breakdown voltages for Avalanche Breakdown and Zener Breakdown?
- At moderate reverse bias conditions under relatively low doping, how should the breakdown behavior change as doping is increased?
- On the right is an image of a Staircase APD ; how is the Avalanche behavior enhanced with this design? How would this affect the magnitude of the breakdown voltage?



Metal-Semiconductor Junctions

- There are two types of metal-semiconductor contacts: ohmic and rectifying.

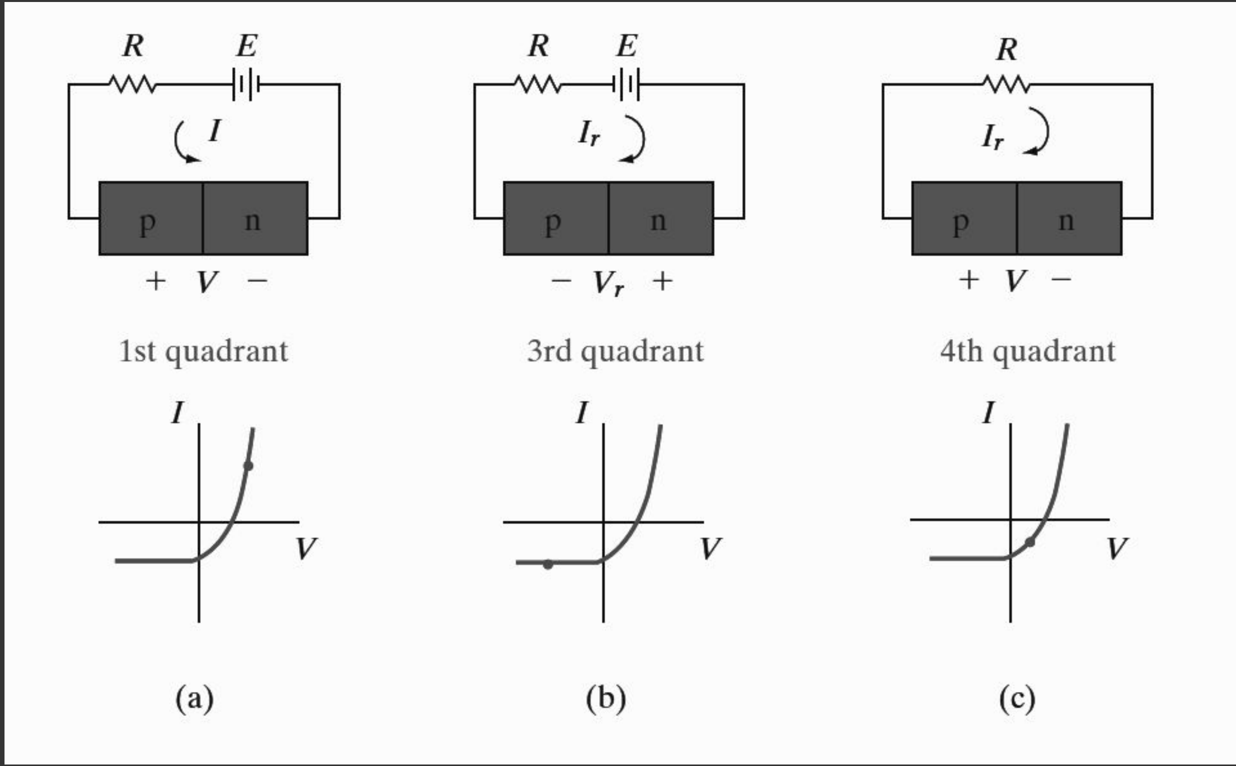
	$\Phi m < \Phi s$	$\Phi m > \Phi s$
N - type	Ohmic	Rectifying
P - type	Rectifying	Ohmic

- In ohmic contacts, an accumulation of majority carriers is needed to align the fermi levels of the semiconductor and the metal. A linear I-V characteristic in both biasing directions.
- In rectifying contacts, a depletion of majority carriers is needed to align the fermi levels of the semiconductor and the metal. There is easy current flow in the forward bias direction, but little current in the reverse bias direction.

Metal-Semiconductor Junctions

A metal and a p-type semiconductor are brought together. The metal work function Φm is less than the semiconductor Φs, but greater than its electron affinity X. Draw the band diagram before and after these two materials come into contact.

Optical Devices



Lasers/LED's

Photodetectors

Solar Cells

Photodiodes

- What are the design constraints for the intrinsic region within a P-I-N diode used for a photodetector?
- What is the maximum value of gain for a photodiode? What testing parameters or material parameters would you change to exceed this limiting gain coefficient in the aforementioned question?
- How would we select the bandgap for a photodiode in order to improve the signal to noise ratio of a photodiode?