# Review Session for ECE 340 Midterm 2 Question Deck

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# Drift/Diffusion

- What is the physical significance of the Continuity Equation? How could we model carrier concentration changes with nonradiative recombination processes with it (SHR, Auger, trap-assisted)?
- Why is there a negative sign for the hole diffusion current but not one for electrons?
- What is the physical significance of the diffusion length? Why does it depend on minority carrier lifetime rather than majority carrier lifetime?
- Draw the majority carrier drift currents along a PN junction in the neutral regions and depletion regions under forward bias. Repeat under low reverse bias conditions.

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# Current Injection

- What limiting assumption is made in order to assume that majority/minority carrier currents don't change in the depletion region?
- As a process engineer, you can either adjust the drive times of only either phosphosilicate glass or borosilicate glass. In order to triple the injection current of a $P^+N$ junction working at a set forward bias, how would you adjust the drive times of one of the furnace steps of the doped glasses? (How would you change the phosphorus or boron doping?)
- What is the physical significance of majority carrier drift current in the neutral regions under forward bias? What does this flux supply?
- Why is it nonphysical to assume that built-in fields and contact potentials only exist in the depletion region? (Multiple reasons)
- Physically, what is occurring in minority carrier extraction? (What is happening to each carrier?)
- Draw carrier distribution profiles under different bias conditions. If the P side is more heavily doped than the N side, how does this affect the magnitude of the carrier concentrations right outside the depletion region and then in the neutral regions?

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# $N^+N$ 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.

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# Graded Junction

An NP junction follows a linear grading doping profile from $N_D$ in the N region to $N_A$ in the P region. Assume the linear grading positions fall exactly within the bounds of the depletion region and that the point of minimal background doping occurs at the metallurgical junction

- Draw the charge density profile
- Draw the electric field profile
- Draw the voltage profile
- To follow this doping profile, how do the Fermi levels vary within each side of the junction?

# Capacitance

- In what regime for voltage conditions would junction capacitance dominate over diffusion capacitance and vice versa?
- In a one-sided step junction, which doping level can be measured and why? Derive how this would be done
- Derive diffusion capacitance using charge storage model
- Why are capacitive effects harmful for high-speed devices?

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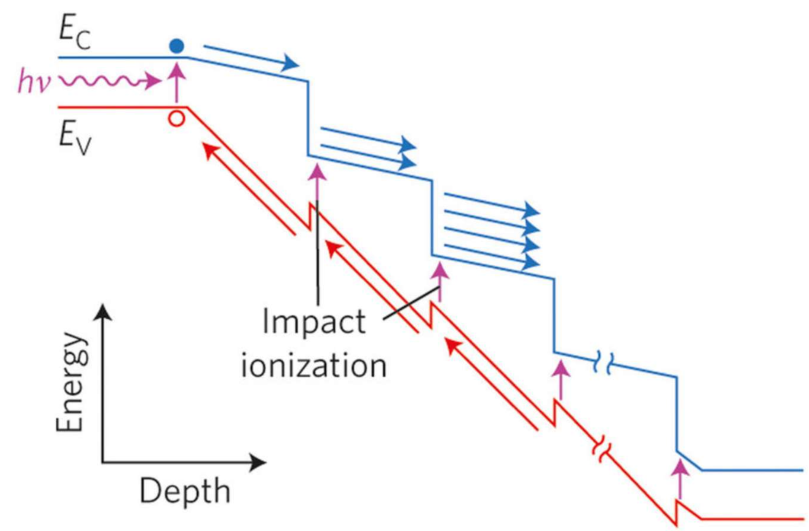
# Breakdown

- 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?
- For low noise APDs, the ionization coefficient of one carrier (electron or holes) is designed to be significantly higher than the other. How does this change a schematic of how impact ionization is depicted in Avalance breakdown?




Ren, Min et al. "AlInAsSb/GaSb Staircase Avalanche Photodiode". *Applied Physics Letters* 108.8 (2016):

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# 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?
- How could you tune different voltage conditions in order to measure the multiplication factor of an APD just by measuring responsivity values?

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# Optoelectronics

- What are the three processes that describe generation and recombination for electrons and holes for a laser? Show the expressions for these rates as a function of carrier concentration, optical field density, and Einstein Coefficients
- For a PN junction photodiode, show the corresponding IV curves respectively for $h\nu$>$E_g$ and $h\nu$ <$E_g$ for $g_3$>$g_2$>$g_1$>$g_0$=0 (A total of 8 curves)
- What's the advantage of quaternary alloys over ternary alloys for optoelectronic design and processing?
- Why are GaP and AlAs not used for blue light-emitting applications over GaN especially when GaP and AlAs occur more abundantly as zincblende crystals over wurtzite?
- Who discovered III-V oxidation (a technique used to form the insulating layers of VCSELs)?
- Who was John Dallesasse's advisor?

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# Optoelectronics

- Say we have a GaAs PN junction with ohmic contacts on both sides. If we shine light on the solar cell, how come there is a split in the quasi-fermi levels even when no external voltage was applied to the device? What is this effect called, and what is the maximum voltage that can be generated from this effect?
- How come EHPs generated due to photon excitation can occur in a width greater than the depletion region?
- What are the tradeoffs in doping too high or too low for efficient carrier collection for a solar cell?

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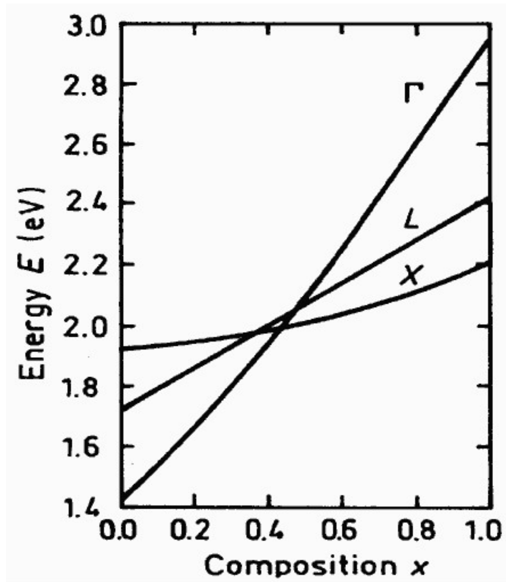
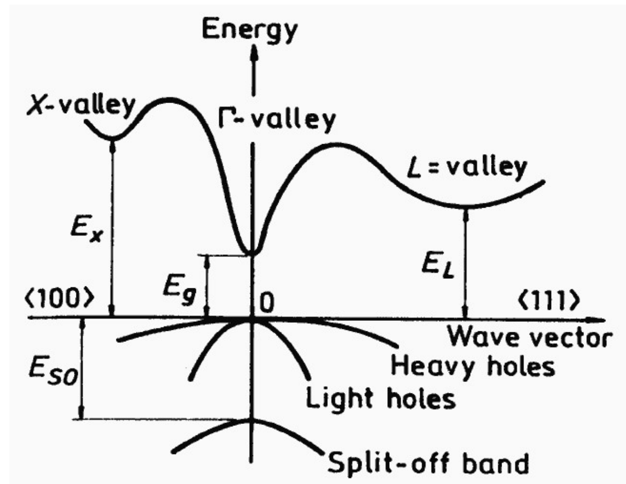
# Optoelectronics

- On the right is an image of the different bandgaps at different symmetry locations of $Al_xGa_{1-x}As$ as a function of concentration. What concentration range can you use $Al_xGa_{1-x}As$ efficiently for light generation? Why can't we tune green and blue wavelengths with this material?

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# Schottky Barriers

- Do we have to worry about charge storage effects with Schottky diodes? Why or why not?
- Say we want to make a P type Ohmic contact to silicon with a metal with a workfunction of 4.04 eV. What is the threshold doping level above which carriers will start to become depleted from silicon?
- Without using any applied bias, can you form back to back Ohmic contacts using a moderately doped n type silicon interlayer?
- It is common in III-V compounds that surface states can pin the Fermi level to the mid-gap regardless of doping. How would this affect making contacts to a device?
- How does the tunnel barrier from the metal to the semiconductor depend upon doping?

# Questions?

Email me (beng3@illinois.edu) for questions about these questions or for more review questions