ECE 340
Solid State Electronic Devices

M,W,F 12:00-12:50 (X), 2015 ECEB

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ECE Illinois
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

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Today's Discussion

- p-n Junctions (Continued)
- Assignments
- Topics for Next Lecture

Tentative Schedule [2]

FEB 19 Quasi-Fermi levels and photoconductive devices	FEB 21 Carrier diffusion	FEB 23 Built-in fields, diffusion and recombination
Feb 26 Review, discussion, problems (2/27 exam)	FEB 28 Steady state carrier injection, diffusion length	MAR 2 p-n junctions in equilibrium & contact potential
MAR 5 p-n junction Fermi levels and space charge	MAR 7 Continue p-n junction space charge	MAR 9 NO CLASS (EOH)
MAR 12 p-n junction current flow	MAR 14 Carrier injection and the diode equation	MAR 16 Minority and majority carrier currents
3/19-3/23 Spring Break MAR 26 Reverse-bias breakdown	MAR 28 Stored charge, diffusion and junction capacitance	MAR 30 Photodiodes, I-V under illumination

Subject to Change

Majority and Minority Currents

Electron & Hole Currents

Ideal Diode Equation

$$I = \frac{qAD_p}{L_p}\Delta p_n + \frac{qAD_n}{L_n}\Delta n_p = qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)\left(e^{qV/kT} - 1\right)$$

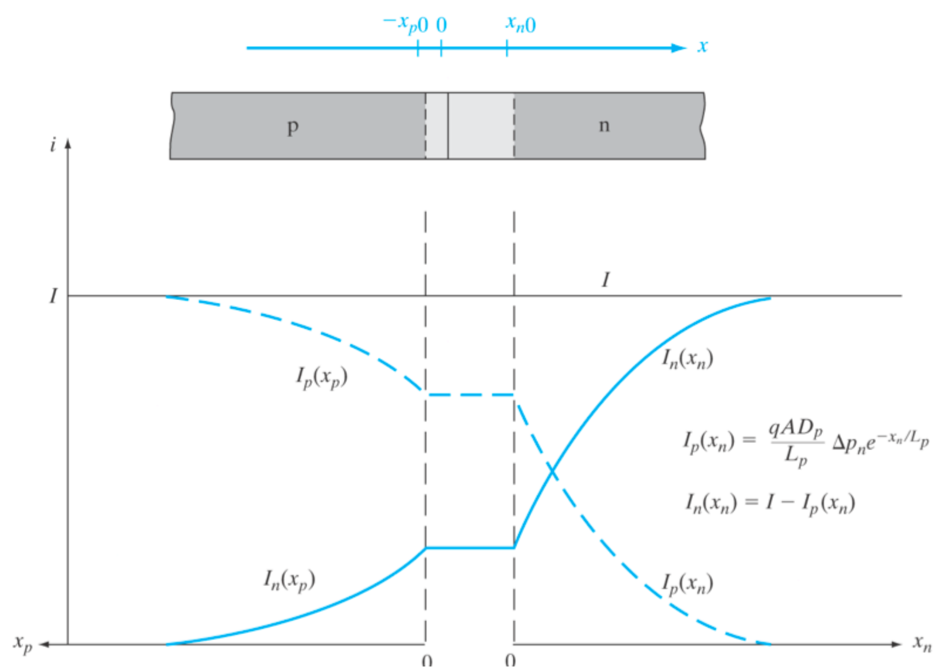
Defining $I_o = qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)$, $I = I_o\left(e^{qV/kT} - 1\right)$

$$I = qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)\left(e^{qV/kT} - 1\right) = I_o\left(e^{qV/kT} - 1\right)$$

Under large reverse bias $\left(V_r \gg \frac{kT}{q}\right)$, $\left(e^{-qV_r/kT} - 1\right) \approx -1$ so

$$I = -qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right) = -I_o$$

Current Components



Majority Carrier Current: n-Side

Calculation of Majority Carrier Current :

$$I_{tot} = qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)\left(e^{qV/kT} - 1\right)$$

$$= I_{n_n} + I_{p_n} = I_n(x_n) + I_p(x_n) \quad \Leftarrow \quad \text{majority carrier + minority carrier current}$$

$$= I_n(x_n) + qA\frac{D_p}{L_p}p_n e^{-x_n/L_p}\left(e^{qV/kT} - 1\right)$$

so:

$I_{n_n} \equiv$ Majority Carrier Current

$I_{p_n} \equiv$ Minority Carrier Current

$I_n(x_n) \equiv$ Majority Carrier Current Referenced to Depletion Region Edge

$I_p(x_n) \equiv$ Minority Carrier Current Referenced to Depletion Region Edge

Majority Carrier Current: n-Side

$$I_{tot} = I_n(x_n) + qA\frac{D_p}{L_p}p_n e^{-x_n/L_p}\left(e^{qV/kT}-1\right)$$

so:

$$I_n(x_n) = I_{tot} - I_{p_n} = \left[qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)\left(e^{qV/kT}-1\right)\right] - \left[qA\frac{D_p}{L_p}p_n e^{-x_n/L_p}\left(e^{qV/kT}-1\right)\right]$$

$$= qA\left[\frac{D_p}{L_p}\left(1-e^{-x_n/L_p}\right)p_n + \frac{D_n}{L_n}n_p\right]\left(e^{qV/kT}-1\right)$$

where x_n is the coordinate system with $\mathrm{x}_n = 0$ at the edge of the n-side depletion region

Relative to the "x" coordinate system with the origin at the metallurgical junction:

$$I_n(x) = qA\left[\frac{D_p}{L_p}\left(1-e^{-(x-\bar{x}_n)/L_p}\right)p_n + \frac{D_n}{L_n}n_p\right]\left(e^{qV/kT}-1\right)$$

where $\bar{x}_n$ is the width of the depletion region on the n-side of the junction

Majority Carrier Current: p-Side

Calculation of Majority Carrier Current :

$$I_{tot} = qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)\left(e^{qV/kT} - 1\right)$$

$$= I_{p_p} + I_{n_p} = I_n(x_p) + I_p(x_p) \quad \Leftarrow \quad \text{majority carrier + minority carrier current}$$

$$= I_p(x_p) + qA\frac{D_n}{L_n}n_p e^{-x_p/L_n}\left(e^{qV/kT} - 1\right)$$

so:

$I_{p_p} \equiv$ Majority Carrier Current

$I_{n_p} \equiv$ Minority Carrier Current

$I_p(x_p) \equiv$ Majority Carrier Current Referenced to Depletion Region Edge

$I_n(x_p) \equiv$ Minority Carrier Current Referenced to Depletion Region Edge

x_p is a transformed coordinate system: $x_p = -x - \overline{x}_p$

where:

The "x" coordinate system is the + going system referenced to the metallurgical junction

$\overline{x}_p$ is the p-side depletion region width

Majority Carrier Current: p-side

$$I_{tot} = I_p(x_p) + qA\frac{D_n}{L_n} n_p e^{-x_p/L_n}\left(e^{qV/kT} - 1\right)$$

so:

$$I_p(x_p) = I_{tot} - I_{n_p} = \left[qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)\left(e^{qV/kT} - 1\right)\right] - \left[qA\frac{D_n}{L_n}n_p e^{-x_p/L_n}\left(e^{qV/kT} - 1\right)\right]$$

$$= qA\left[\frac{D_p}{L_p}\left(1 - e^{-x_p/L_p}\right)p_n + \frac{D_p}{L_p}p_n\right]\left(e^{qV/kT} - 1\right)$$

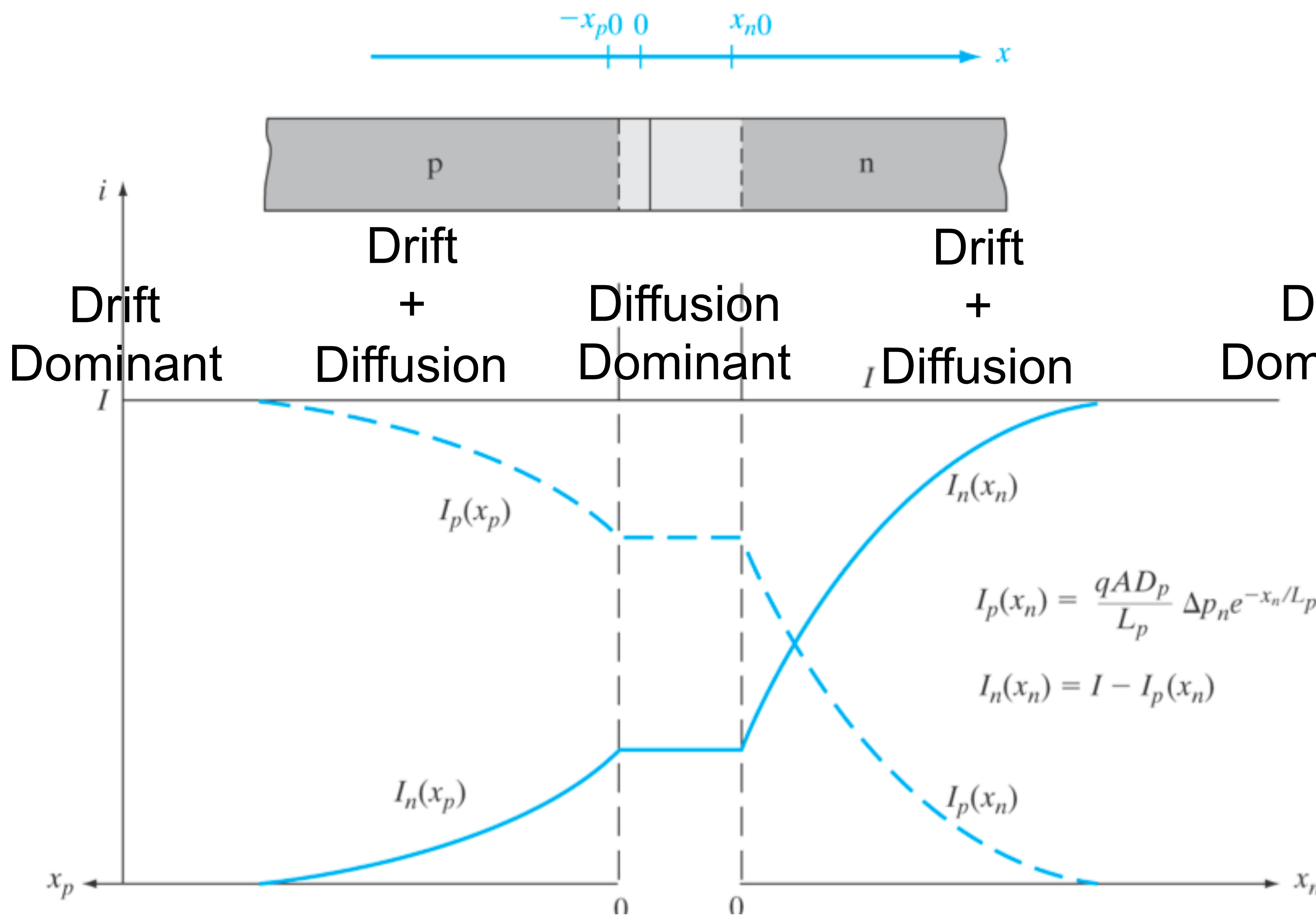
where x_p is the negative-going coordinate system with $x_p = 0$

at the edge of the n-side depletion region

Referenced to Metallurgical Junction and + going System:

$$I_p(x_p) = qA\left[\frac{D_p}{L_p}\left(1 - e^{x + \overline{x}_p/L_p}\right)p_n + \frac{D_p}{L_p}p_n\right]\left(e^{qV/kT} - 1\right)$$

Drift & Diffusion in Forward Bias



Example

Example: p-n Diode

Determine the current at bias voltages of +0.5 and -0.5V.

Silicon p-n junction with an area of 10^{-4} cm^2 at 300K:

$$I = qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)\left(e^{qV/kT}-1\right) = I_o\left(e^{qV/kT}-1\right)$$

Calculate equilibrium minority carrier concentrations:

$$p_n = \frac{n_i^2}{n_n} = \frac{\left(1.5\times10^{10}\right)^2}{10^{15}} = 2.25\times10^5\,cm^{-3}$$

$$n_p = \frac{n_i^2}{p_p} = \frac{\left(1.5\times10^{10}\right)^2}{10^{17}} = 2.25\times10^3\,cm^{-3}$$

Calculate the **MINORITY CARRIER** diffusion coefficient and diffusion length:

$$D_p = \frac{kT}{q}\mu_p = 0.0259\times450 = 11.66 \text{ cm}^2/\text{s} \leftarrow \text{ holes on n-side}$$

$$D_n = \frac{kT}{q}\mu_n = 0.0259\times700 = 18.13 \text{ cm}^2/\text{s} \leftarrow \text{ electrons on p-side}$$

$$L_p = \sqrt{D_p\tau_p} = \sqrt{11.66\times\left(10\times10^{-6}\right)} = 1.08\times10^{-2} \text{ cm}$$

$$L_n = \sqrt{D_n\tau_n} = \sqrt{18.13\times\left(0.1\times10^{-6}\right)} = 1.35\times10^{-3} \text{ cm}$$

Calculate I_o :

$$I_o = qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)$$

$$= \left(1.6\times10^{-19}\right)\times\left(0.0001\right)\left(\frac{11.66}{0.0108}\left(2.25\times10^5\right) + \frac{18.13}{0.00135}\left(2.25\times10^3\right)\right)$$

$$= 4.370\times10^{-15}\text{ A} = 4.370 \text{ fA}$$

Current at a voltage of +0.5 V: $I = I_o\left(e^{0.5/0.0259}-1\right) \approx 1.058\times10^{-6}A$

Current at a voltage of -0.5 V: $I \approx -I_o = -4.37\times10^{-15}A$

p-side	n-side
N_a=10^{17} cm^{-3}	N_d=10^{15} cm^{-3}
τ_n=0.1 μs	τ_p=10 μs
μ_p=200 cm^2/V-s	μ_n=1300 cm^2/V-s
μ_n=700 cm^2/V-s	μ_p=450 cm^2/V-s

Key Point:

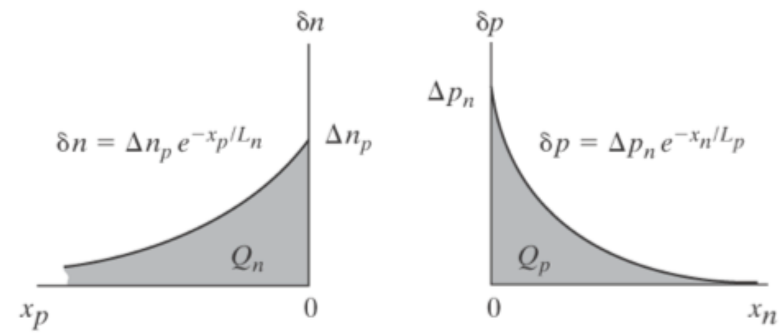
- Use the correct mobility in the calculation of D_p and D_n
- Minority carrier mobility

Charge Control Model

Another Derivation of the Ideal Diode Equation

Charge Control Approximation

- In steady state, the rate at which we replenish charge across the x_n=0 or x_p=0 plane must equal the amount of minority carrier charge lost through recombination in an interval of time
- The rate at which charge is lost is equal to the total amount of charge divided by the charge lifetime



$$Q_n = -qA\int_0^\infty \delta n(x_p)\, dx_p \qquad Q_p = qA\int_0^\infty \delta p(x_n)\, dx_n$$

$$I_n(x_p{=}0) = \frac{Q_n}{\tau_n} = \frac{-qAL_n}{\tau_n}\Delta n_p \qquad I_p(x_n{=}0) = \frac{Q_p}{\tau_p} = \frac{qAL_p}{\tau_p}\Delta p_n$$

$$Q_p = qA\int_0^\infty \delta p(x_n)\,dx_n = qA\Delta p_n \int_0^\infty e^{-x_n/L_p}\,dx_n$$
$$= qA\Delta p_n L_p$$

$$Q_n = qA\int_0^\infty \delta n(x_p)\,dx_p = qA\Delta n_p \int_0^\infty e^{-x_p/L_n}\,dx_p$$
$$= qA\Delta n_p L_n$$

$$I = I_p(x_n{=}0) - I_n(x_p{=}0) = qA\left(\frac{D_p}{L_p}\Delta p_n + \frac{D_n}{L_n}\Delta n_p\right)$$
$$= qA\left(\frac{D_p p_n}{L_p} + \frac{D_n n_p}{L_n}\right)(e^{qV/kT} - 1)$$

Recall that: $L_n \equiv \sqrt{D_n \tau_n}$ and $L_p \equiv \sqrt{D_p \tau_p}$

so: $\tau_n = \dfrac{L_n^2}{D_n}$ and $\tau_p = \dfrac{L_p^2}{D_p}$

Note: x_p and x_n coordinate systems

Summary of Models

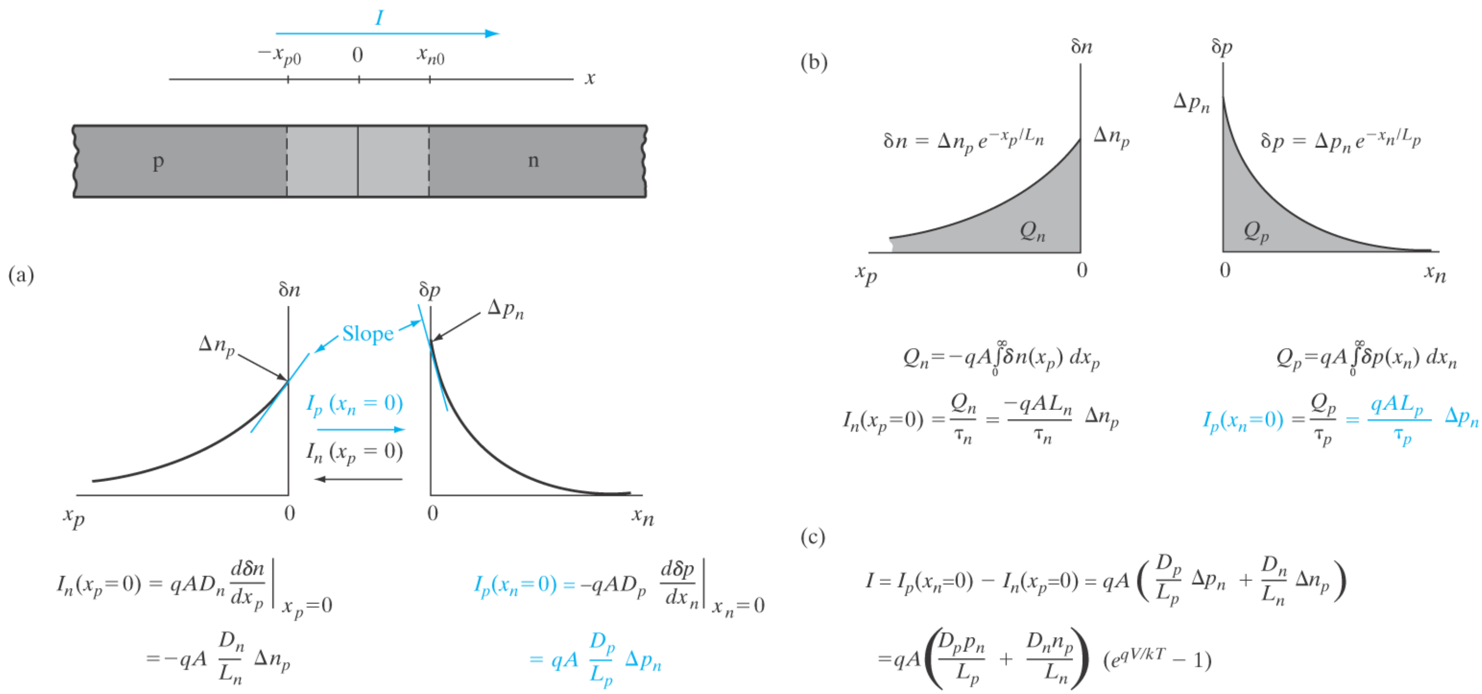
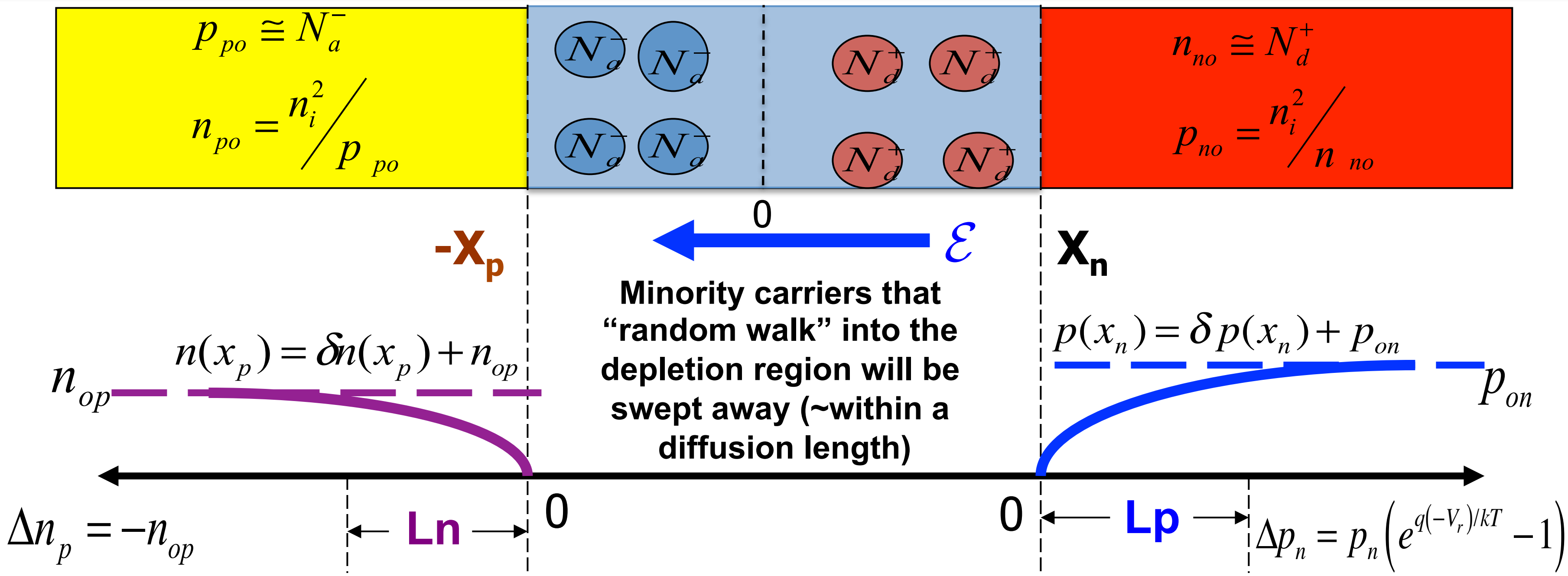


Figure 5.16

Two methods for calculating junction current from the excess minority carrier distributions: (a) diffusion currents at the edges of the transition region; (b) charge in the distributions divided by the minority carrier lifetimes; (c) the diode equation.

Reverse Bias

Reverse Bias: Drift Term Dominant



$$\Phi_n(drift) >> \Phi_n(diff), \Phi_p(drift) >> \Phi_p(diff) \qquad \simeq -p_{on}$$

$$\Delta n_p = n_p(-x_p) - n_{op}$$

$$\Delta n_p = 0 - n_{op} = -n_{op}$$

$$\delta n(x_p) = -n_{op} e^{-x_p/Ln}$$

$$I_n(x_p) = +qAD_n \frac{d\delta n(x_p)}{dx_p}$$

$$I_n(x_p) = -qA \frac{D_n}{L_n} \delta n(x_p)$$

Combining Terms:

$$I = I_p(x_n = 0) + I_n(x_n = 0)_{x_n axis} = I_p(x_n = 0) - I_n(x_p = 0)_{x_p axis} \text{ so:}$$

$$I = \frac{qAD_p}{L_p}\Delta p_n + \frac{qAD_n}{L_n}\Delta n_p = qA\left(\frac{D_p}{L_p}(-p_{no}) + \frac{D_n}{L_n}(-n_{po})\right)$$

$$= -qA\left(\frac{D_p}{L_p}(p_{no}) + \frac{D_n}{L_n}(n_{po})\right) = -I_0$$

$$\Delta p_n = p_n(x_n) - p_{on}$$

$$\Delta p_n = 0 - p_{on} = -p_{on}$$

$$\delta p(x_n) = \Delta p_n e^{-x_n/L_p} = -p_{no} e^{-x_n/L_p}$$

$$I_p(x_n) = -qAD_p \frac{d\delta p(x_n)}{dx_n}$$

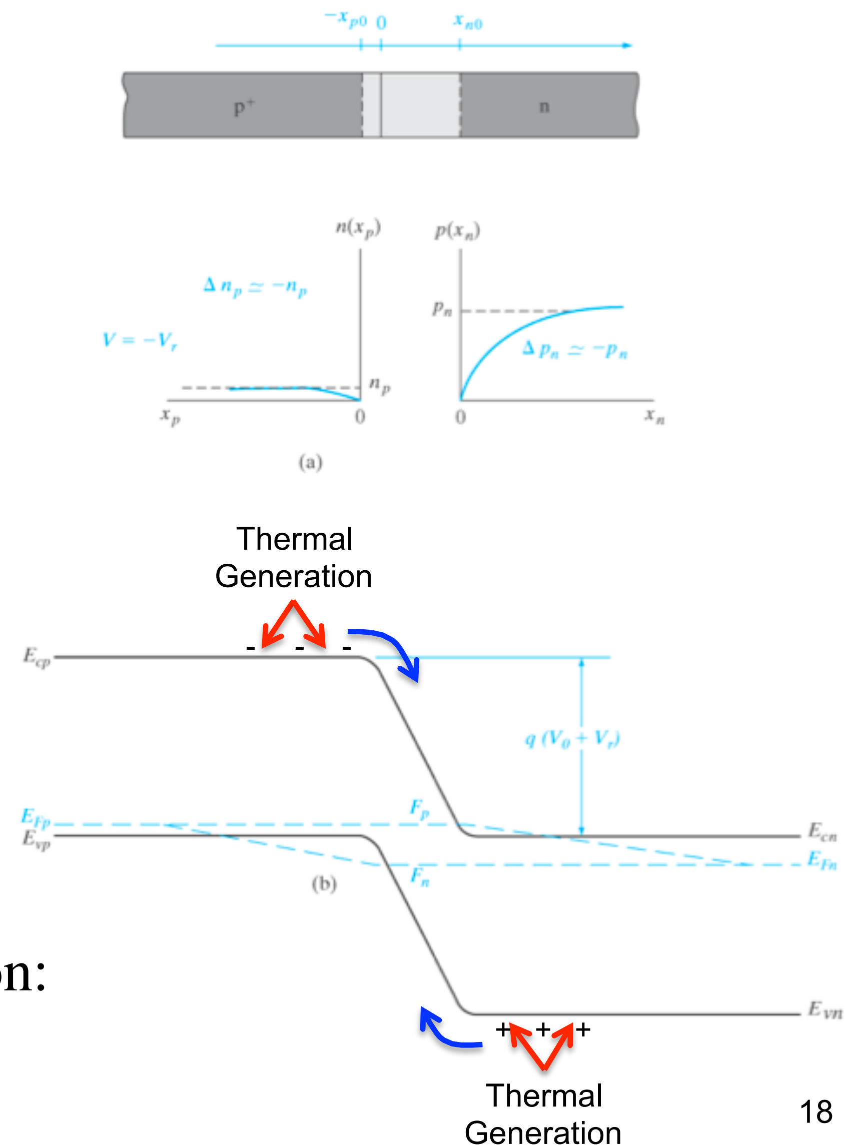
$$I_p(x_n) = qA \frac{D_p}{L_p} \delta p(x_n)$$

Reverse Bias Quasi Fermi Levels

$$\Delta p_n = p_n\left(e^{q(-V_r)/kT} - 1\right) \simeq -p_n \quad \text{for } V_r \gg kT/q$$

Similarly: $\Delta n_p \simeq -n_p$

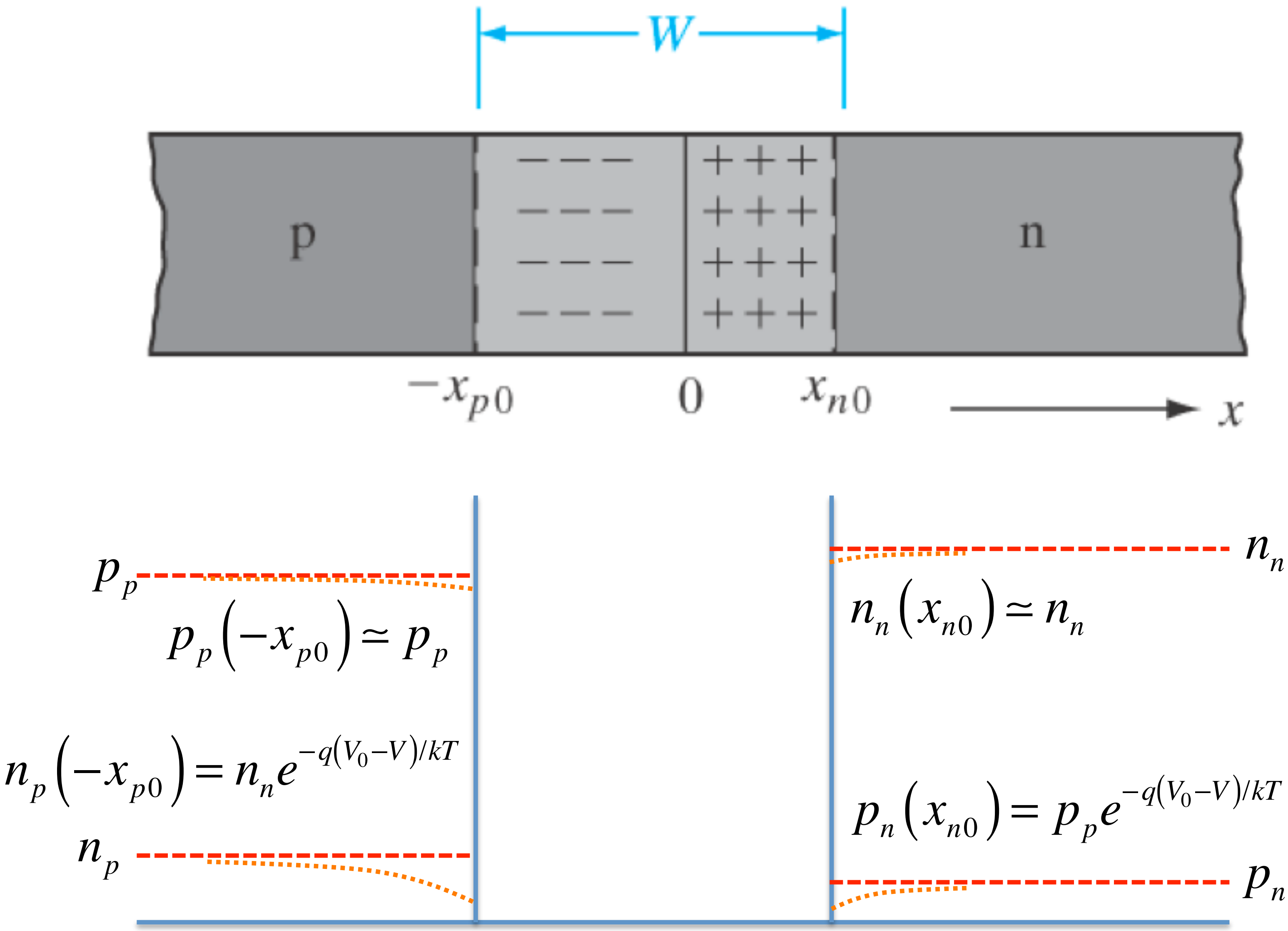
- Minority carrier concentration approaches zero at the edge of the depletion region
- This effect is termed "minority carrier extraction"
- The reverse saturation current is a drift-dominated current, but the minority carriers arrive at the depletion region by way of diffusion



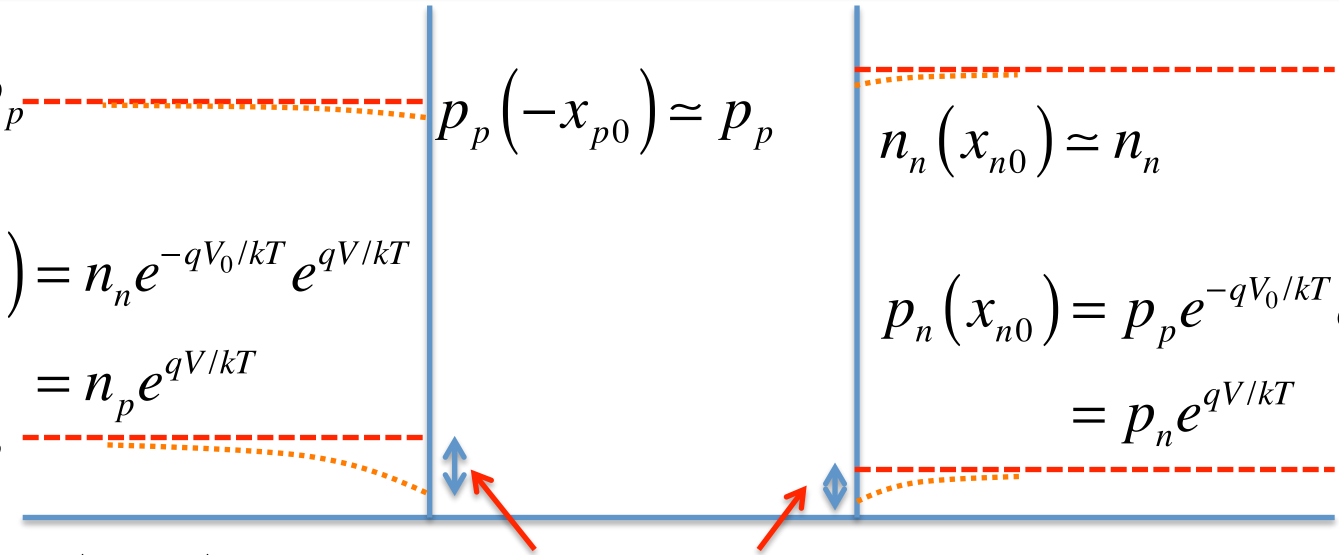
Reverse Bias, Edge of Depletion Region:

$$pn = n_i^2 e^{(F_n - F_p)/kT} \approx 0$$

Reverse Bias Charge Distribution



Reverse Bias Charge Distribution



$$p_p\left(-x_{p0}\right) \simeq p_p$$

$$n_n\left(x_{n0}\right) \simeq n_n$$

$$n_p\left(-x_{p0}\right) = n_n e^{-qV_0/kT} e^{qV/kT} = n_p e^{qV/kT}$$

$$p_n\left(x_{n0}\right) = p_p e^{-qV_0/kT} e^{qV/kT} = p_n e^{qV/kT}$$

$$n_p\left(-x_{p0}\right) - n_p\left(-\infty\right) = \Delta n$$

$$n_p e^{qV/kT} - n_p =$$

$$n_p\left(e^{qV/kT} - 1\right) =$$

$$-n_p \simeq$$

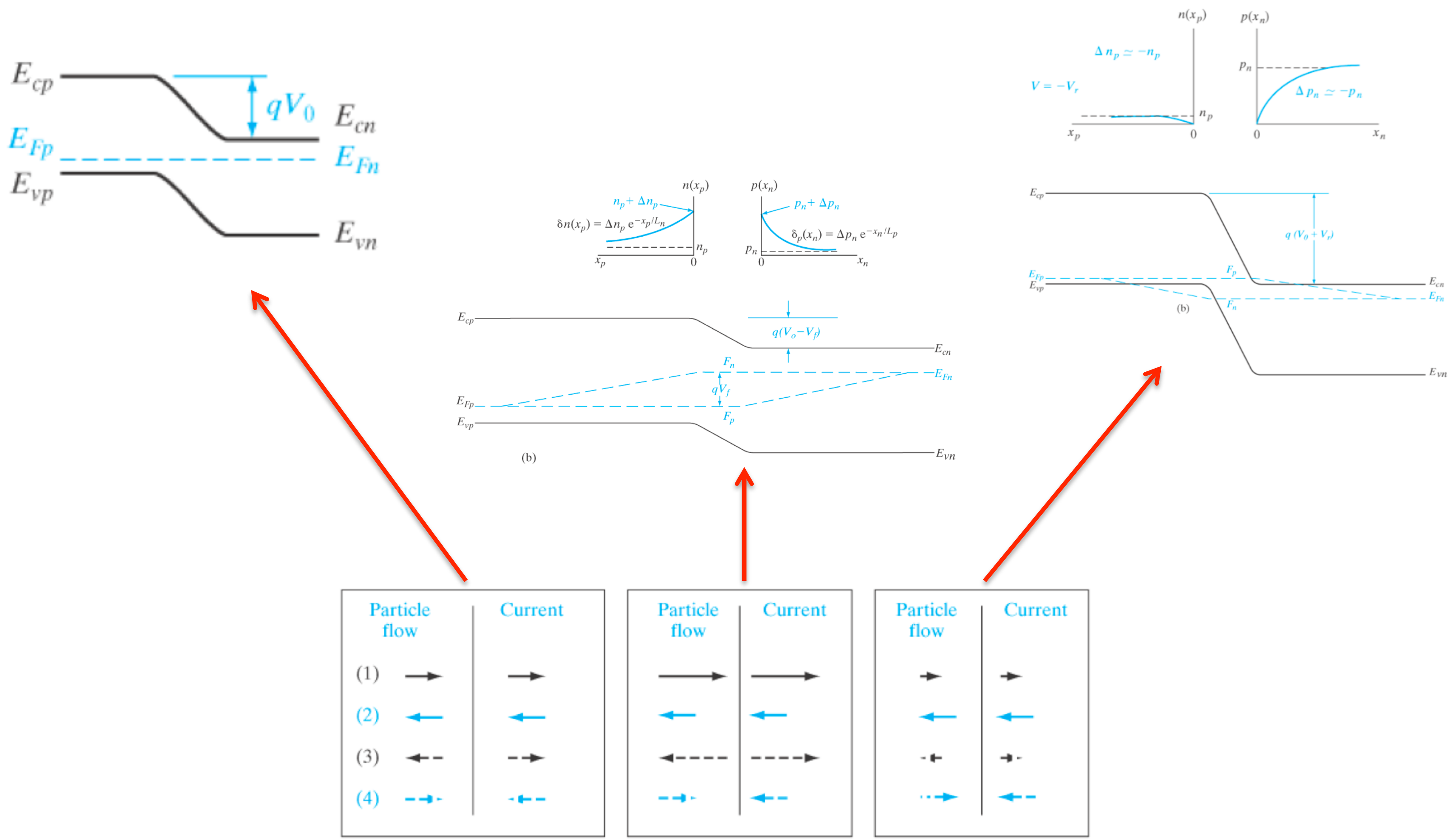
$$\Delta p = p_n\left(x_{n0}\right) - p_n\left(\infty\right)$$

$$= p_n e^{qV/kT} - p_n$$

$$= p_n\left(e^{qV/kT} - 1\right)$$

$$\simeq -p_n$$

Junction Currents: Revisited



(1) Hole diffusion
(2) Hole drift
(3) Electron diffusion
(4) Electron drift

Assignments

Assignments

- Homework assigned every Friday, due following Friday
- Reading from Streetman's book:
  - Mon 3/5: §'s 5.2, 5.2.1, 5.2.2, 5.2.3
  - Wed 3/7: § 5.2.3
- Chapters 3, 4, and 5 in Pierret cover similar material

Assignments

- Homework assigned every Friday, due following Friday
- Reading from Streetman's book:
  - Mon 3/12: §'s 5.2.3, 5.3, 5.3.1
  - Wed 3/14: § 5.3.2
  - Wed 3/16: §'s 5.3.2, 5.3.3
- Chapters 3, 4, and 5 in Pierret cover similar material

Topics for Next Lecture

Outline, 3/26/18

- Continue pn Junctions

Thank You for Listening!

Instructional Objectives (1)

By the time of exam No. 1 (after 17 lectures), the students should be able to do the following:

1. Outline the classification of solids as metals, semiconductors, and insulators and distinguish direct and indirect semiconductors.
2. Determine relative magnitudes of the effective mass of electrons and holes from an E(k) diagram.
3. Calculate the carrier concentration in intrinsic semiconductors.
4. Apply the Fermi-Dirac distribution function to determine the occupation of electron and hole states in a semiconductor.
5. Calculate the electron and hole concentrations if the Fermi level is given; determine the Fermi level in a semiconductor if the carrier concentration is given.
6. Determine the variation of electron and hole mobility in a semiconductor with temperature, impurity concentration, and electrical field.
7. Apply the concept of compensation and space charge neutrality to calculate the electron and hole concentrations in compensated semiconductor samples.
8. Determine the current density and resistivity from given carrier densities and mobilities.
9. Calculate the recombination characteristics and excess carrier concentrations as a function of time for both low level and high level injection conditions in a semiconductor.
10. Use quasi-Fermi levels to calculate the non-equilibrium concentrations of electrons and holes in a semiconductor under uniform photoexcitation.
11. Calculate the drift and diffusion components of electron and hole currents.
12. Calculate the diffusion coefficients from given values of carrier mobility through the Einstein's relationship and determine the built-in field in a non-uniformly doped sample.

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Instructional Objectives (2)

By the time of Exam No.2 (after 32 lectures), the students should be able to do all of the items listed under A, plus the following:

13. Calculate the contact potential of a p-n junction.
14. Estimate the actual carrier concentration in the depletion region of a p-n junction in equilibrium.
15. Calculate the maximum electrical field in a p-n junction in equilibrium.
16. Distinguish between the current conduction mechanisms in forward and reverse biased diodes.
17. Calculate the minority and majority carrier currents in a forward or reverse biased p-n junction diode.
18. Predict the breakdown voltage of a p+-n junction and distinguish whether it is due to avalanche breakdown or Zener tunneling.
19. Calculate the charge storage delay time in switching p-n junction diodes.
20. Calculate the capacitance of a reverse biased p-n junction diode.
21. Calculate the capacitance of a forward biased p-n junction diode.
22. Predict whether a metal-semiconductor contact will be a rectifying contact or an ohmic contact based on the metal work function and the semiconductor electron affinity and doping.
23. Calculate the electrical field and potential drop across the neutral regions of wide base, forward biased p+-n junction diode.
24. Calculate the voltage drop across the quasi-neutral base of a forward biased narrow base p+-n junction diode.
25. Calculate the excess carrier concentrations at the boundaries between the space-charge region and the neutral n- and p-type regions of a p-n junction for either forward or reverse bias.

Instructional Objectives (3)

By the time of the Final Exam, after 44 class periods, the students should be able to do all of the items listed under A and B, plus the following:

26. Calculate the terminal parameters of a BJT in terms of the material properties and device structure.
27. Estimate the base transport factor “B” of a BJT and rank-order the internal currents which limit the gain of the transistor.
28. Determine the rank order of the electrical fields in the different regions of a BJT in forward active bias.
29. Calculate the threshold voltage of an ideal MOS capacitor.
30. Predict the C-V characteristics of an MOS capacitor.
31. Calculate the inversion charge in an MOS capacitor as a function of gate and drain bias voltage.
32. Estimate the drain current of an MOS transistor above threshold for low drain voltage.
33. Estimate the drain current of an MOS transistor at pinch-off.
34. Distinguish whether a MOSFET with a particular structure will operate as an enhancement or depletion mode device.
35. Determine the short-circuit current and open-circuit voltage for an illuminated p/n junction solar cell.

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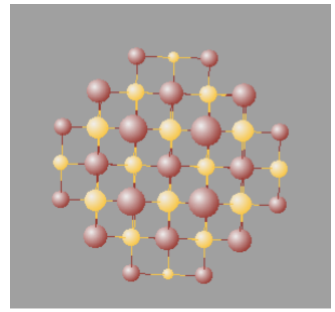
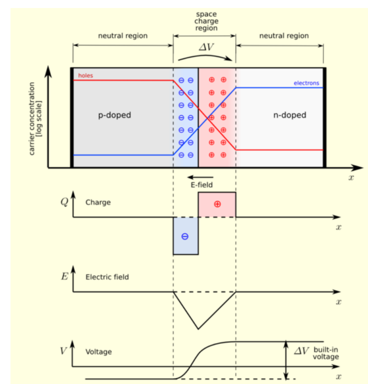
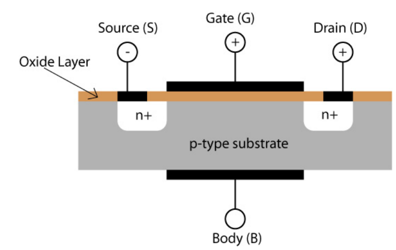
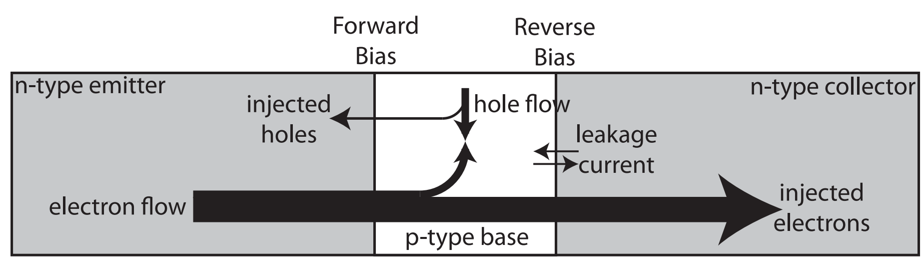
Course Purpose & Objectives

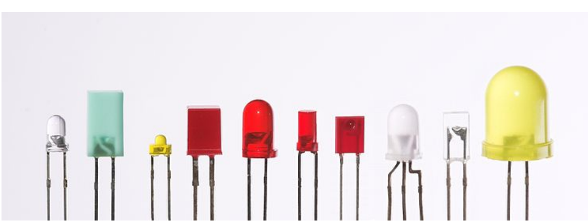
- Introduce key concepts in semiconductor materials
- Provide a basic understanding of p-n junctions
- Provide a basic understanding of light-emitting diodes and photodetectors
- Provide a basic understanding of field effect transistors
- Provide a basic understanding of bipolar junction transistors











Tentative Schedule [1]

	JAN 17 Course overview	JAN 19 Intro to semiconductor electronics
JAN 22 Materials and crystal structures	JAN 24 Bonding forces and energy bands in solids	JAN 26 Metals, semiconductors, insulators, electrons, holes
JAN 29 Intrinsic and extrinsic material	JAN 31 Distribution functions and carrier concentrations	FEB 2 Distribution functions and carrier concentrations
FEB 5 Temperature dependence, compensation	FEB 7 Conductivity and mobility	FEB 9 Resistance, temperature, impurity concentration
FEB 12 Invariance of Fermi level at equilibrium	FEB 14 Optical absorption and luminescence	FEB 16 Generation and recombination

Subject to Change

Tentative Schedule [3]

APR 2 LEDs and Diode Lasers	APR 4 Metal-semiconductor junctions	APR 6 MIS-FETs: Basic operation, ideal MOS capacitor
APR 9 MOS capacitors: flatband & threshold voltage	APR 11 Review, discussion, problems (4/12 exam)	APR 13 MOS capacitors: C-V analysis
APR 16 MOSFETs: Output & transfer characteristics	APR 18 MOSFETs: small signal analysis, amps, inverters	APR 20 Narrow-base diode
APR 23 BJT fundamentals	APR 25 BJT specifics	APR 27 BJT normal mode operation
APR 30 BJT common emitter amplifier and current gain	MAY 2 (LAST LECTURE) Review, discussion, problem solving	FINAL EXAM **Date & time to be announced**

Subject to Change

Schedule & Policies

Important Information

- Course Website:
  - http://courses.engr.illinois.edu/ece340/
- Download and Review Syllabus / Course Information from Website!
- Course Coordinator: Prof. John Dallesasse
  - jdallesa@illinois.edu
  - Coordinates schedule, policies, absence issues, homework, quizzes, exams, etc.
- Contact Information and Office Hours for All ECE340 Professors & TAs in Syllabus
- Lecture Slides: Click on "(Sec. X)" next to my name in instructor list
- DRES Students: Contact Prof. Dallesasse ASAP
- Textbook:
  - "Solid State Electronic Devices," Streetman & Banerjee, 7th Edition
  - Supplemental: "Semiconductor Device Fundamentals," Pierret
  - Additional reference texts listed in syllabus

Key Points

- Attend Class!
  - 3 unannounced quizzes, each worth 5% of your grade
  - **You must take the quiz in your section**
  - Excused absences must be **pre-arranged** with the course director
  - Absences for illness, etc. need a note from the Dean
    - See policy on absences in the syllabus
- No Late Homework
  - Homework due on the date of an excused absence must be turned in ahead of time
  - You must turn in homework in your section
  - No excused absences for homework assignments
  - Top 10 of 11 homework assignments used in calculation of course grade
    - Do all of them to best prepare for the exams!
- No Cheating
  - Penalties are severe and will be enforced
- Turn Off Your Phone
  - No video recording, audio recording, or photography

Homework

- Assigned Friday, Due Following Friday
  – Due dates shown in syllabus
- Due at Start of Class
- Follow Guidelines in Syllabus
- Peer Discussions Related to Homework are Acceptable and Encouraged
- Directly Copying Someone Else's Homework is Not Acceptable
  – Graders have been instructed to watch for evidence of plagiarism
  – Both parties will receive a "0" on the problem or assignment

Absences

- The absence policy in the syllabus will be strictly enforced
- To receive an excused absence (quiz), you must:
  - Pre-arrange the absence with the course director (valid reason and proof required)
  - Complete an Excused Absence Form at the Undergraduate College Office, Room 207 Engineering Hall (333-0050)
    - The form must be signed by a physician, medical official, or the Emergency Dean (Office of the Dean of Students)
    - The Dean's Office has recently put a strict policy in place (3 documented days of illness)
  - Excused quiz score will be prorated based upon average of completed scores
  - No excused absences are given for homework, but only the best 10 of 11 are used to calculate your final grade
  - Excused absences are not given for exams, except in accordance with the UIUC Student Code
  - Unexcused work will receive a "0"
- Failure to take the final will result in an "incomplete" grade (if excused) or a "0" (if unexcused)

Exams

- Exam I: Tuesday February 27th, 7:30-8:30 pm
- Exam II: Thursday April 12th, 7:30-8:30 pm
- Final Exam: Date/Time To Be Announced
  - Determined by University F&S

Grading

Grading Criterion

Homework	10 %
Quizzes	15 %
Hour Exam I	20 %
Hour Exam II	20 %
Final Exam	35 %
Total	100 %

Historical Grade Trends*

	Spring 2016	Fall 2016	Spring 2017
A's	27 %	28 %	27 %
B's	37 %	26 %	38 %
C's	27 %	25 %	27%
D's	6 %	16 %	4 %
F's	3 %	5 %	4 %

*Past performance is not necessarily indicative of future results

My Recommendations

- Read the syllabus and information posted on the course website
- **Attend class** & participate
- Attend office hours (TA and Professors)
- **Read the book**
- Re-read the book
- Look at and read selected portions of the supplemental texts
- Form study groups to review concepts and discuss high-level approaches for solving homework problems
  - Don't form study groups to copy homework solutions
- **Don't miss any homework, quizzes, or exams**
  - It's hard to overcome a zero
- Ask questions in class!

Instructional Objectives (1)

By the time of exam No. 1 (after 17 lectures), the students should be able to do the following:

✔1. Outline the classification of solids as metals, semiconductors, and insulators and distinguish direct and indirect semiconductors.

✔2. Determine relative magnitudes of the effective mass of electrons and holes from an E(k) diagram.

✔3. Calculate the carrier concentration in intrinsic semiconductors.

✔4. Apply the Fermi-Dirac distribution function to determine the occupation of electron and hole states in a semiconductor.

✔5. Calculate the electron and hole concentrations if the Fermi level is given; determine the Fermi level in a semiconductor if the carrier concentration is given.

✔6. Determine the variation of electron and hole mobility in a semiconductor with temperature, impurity concentration, and electrical field.

✔7. Apply the concept of compensation and space charge neutrality to calculate the electron and hole concentrations in compensated semiconductor samples.

✔8. Determine the current density and resistivity from given carrier densities and mobilities.

✔9. Calculate the recombination characteristics and excess carrier concentrations as a function of time for both low level and high level injection conditions in a semiconductor.

✔10. Use quasi-Fermi levels to calculate the non-equilibrium concentrations of electrons and holes in a semiconductor under uniform photoexcitation.

✔11. Calculate the drift and diffusion components of electron and hole currents.

✔12. Calculate the diffusion coefficients from given values of carrier mobility through the Einstein's relationship and determine the built-in field in a non-uniformly doped sample.

Plus continuity equation, steady-state carrier injection, and diffusion length

https://my.ece.illinois.edu/courses/description.asp?ECE340

Quiz 1 Statistics

- Average: 8.65
- Standard Deviation: 1.49

Exam I Statistics

- Average (All Sections): 71.88
- Standard Deviation (All Sections): 15.44

Streetman Errata (6th Edition)

- Equation 4-30: "ΔxA" not δxA
- Equation 4-33b: "τ_p" not "τ_n"

Final Exam Schedule

Course	Section	CRN	Date	Day	Start Time	End Time	Room	Exam Type
ECE 340	ALL	ALL	05/04/2018	F	1:30 PM	4:30 PM	1002 Electrical & Computer Eng Bldg	Combined
ECE 340	ALL	ALL	05/04/2018	F	7:00 PM	10:00 PM	2015 Electrical & Computer Eng Bldg	Conflict