ECE 340
Solid State Electronic Devices

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

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Office Hours: Wednesday 13:00 – 14:00

ECE Illinois
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

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Announcements

- Hour Exam II, Thursday 4/12, 7:30-8:30 pm
  - 1002 ECEB (Grainger Auditorium)
  - Conflict: Contact J. Dallesasse Before Monday 4/9
  - Taking exam at DRES-TAC: Contact J. Dallesasse Before Thursday 4/5
- A correction was made to the posed HW
  - Expression for AlGaAs bandgap corrected in 3c

Streetman Errata

- Equation 6-35 in Streetman's "Solid State Electronic Devices" 6th edition has a typo:

Equation in Streetman:

$$C_i = \frac{\varepsilon_s}{W}$$

Corrected Version:

$$C_d = \frac{\varepsilon_s}{W}$$

Today's Discussion

- Metal-Semiconductor Junctions
- LEDs and Lasers
- Assignments
- Topics for Next Lecture

Tentative Schedule [3]

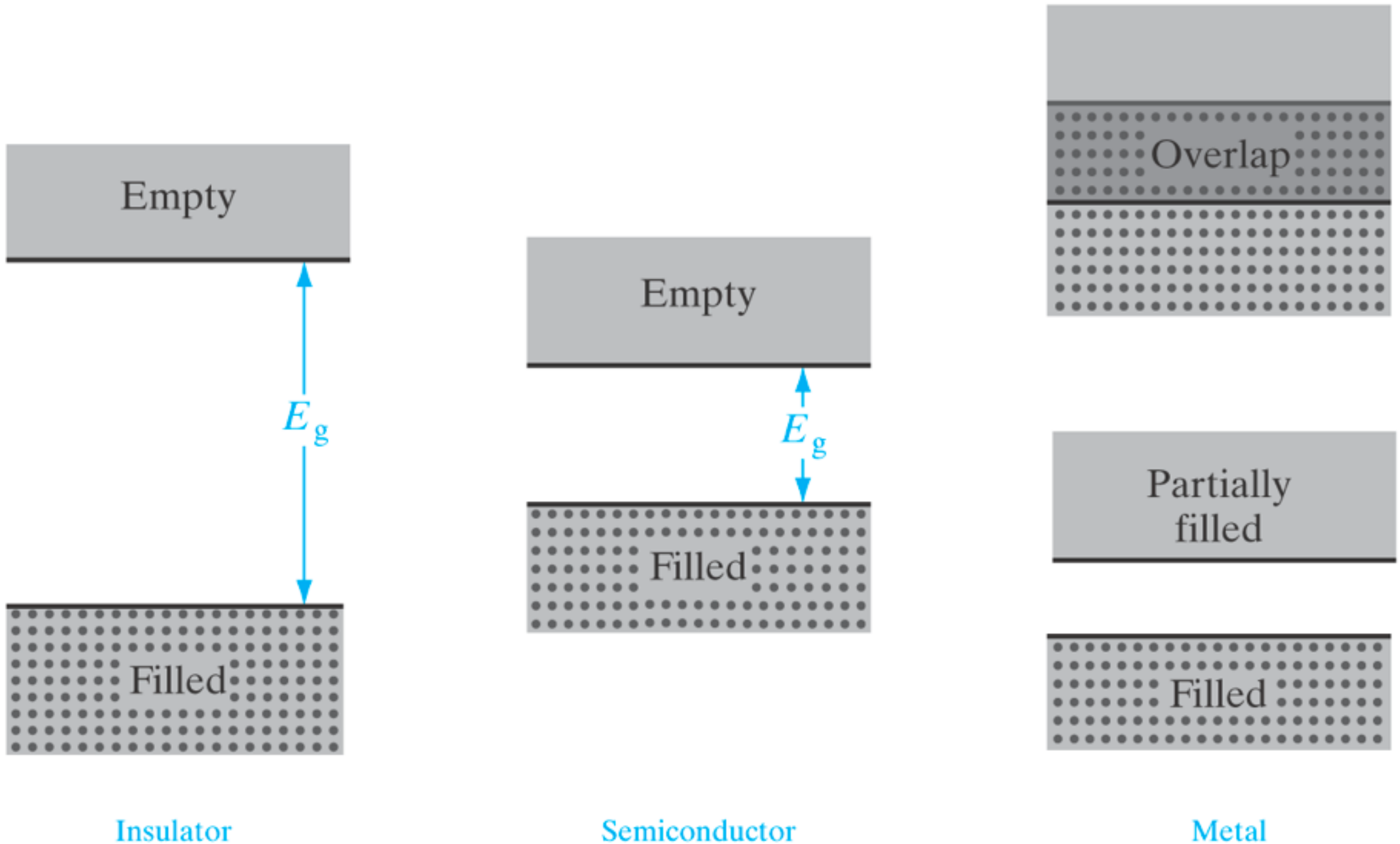
APR 2 LEDs and Diode Lasers	APR 4 Metal-semiconductor junctions	APR 6 MIS-FETs: Basic operation, ideal MOS capacitor
APR 9 MOS capacitors: flatband & threshold voltage	APR 11 Review, discussion, problems (4/12 exam)	APR 13 MOS capacitors: C-V analysis
APR 16 MOSFETs: Output & transfer characteristics	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

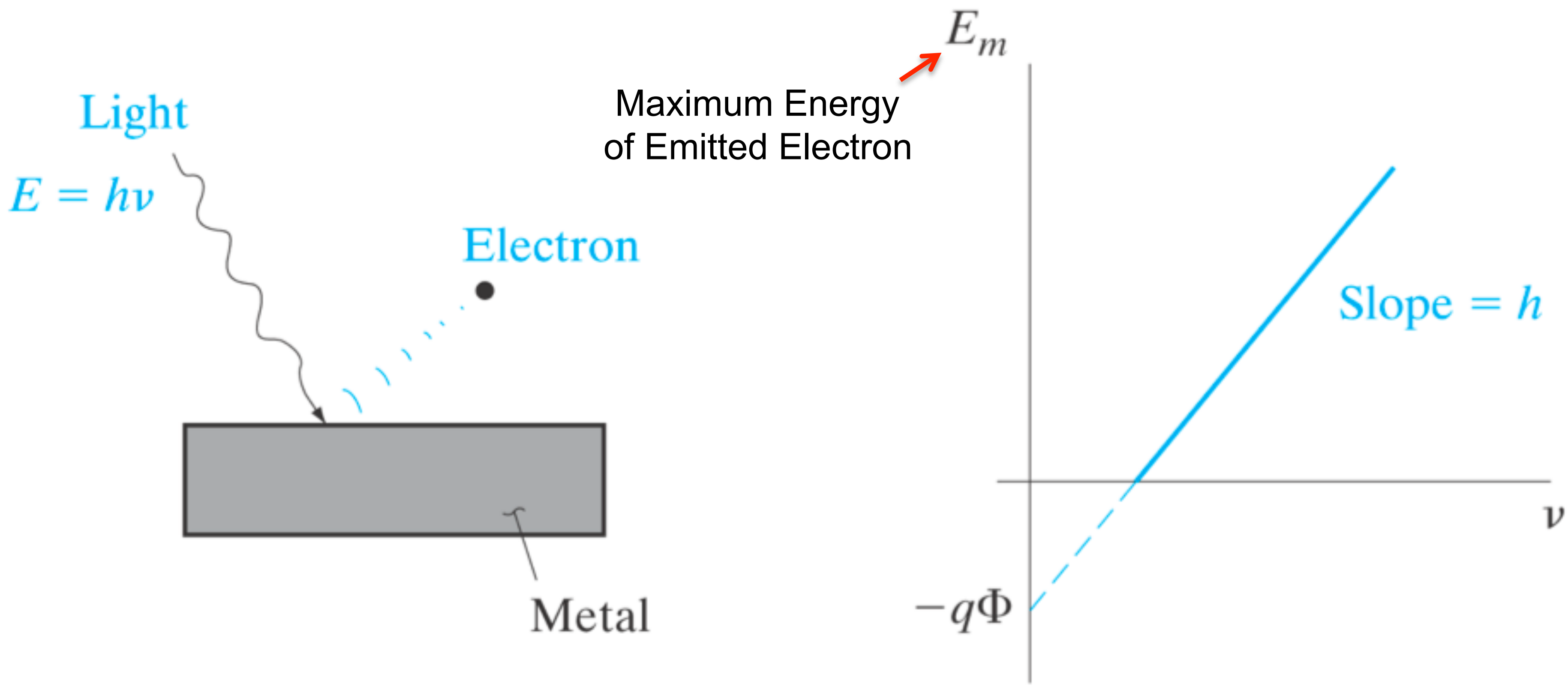
Ideal Metal-Semiconductor Junctions

Schottky Barriers

Reminder: Metal, Semiconductor, Insulator



Reminder: Photoelectric Effect

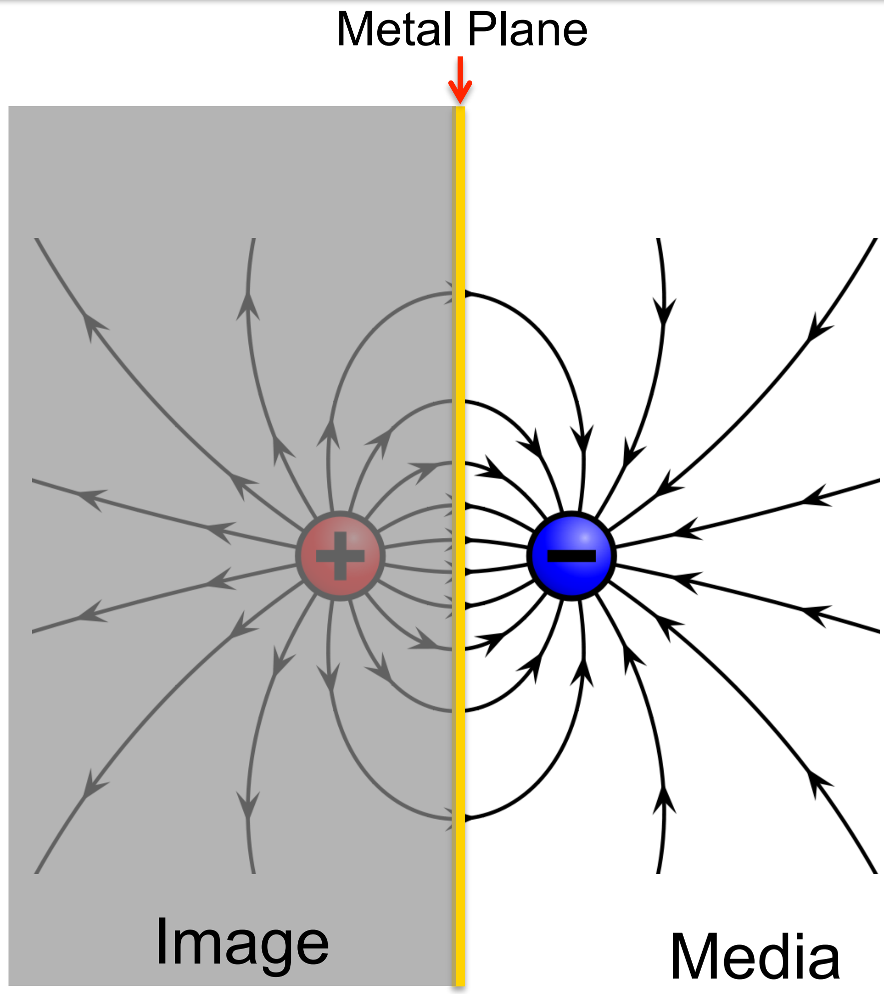


$$E = h\nu - q\Phi$$

$q\Phi$ is the ***Work Function*** of the material

Definitions

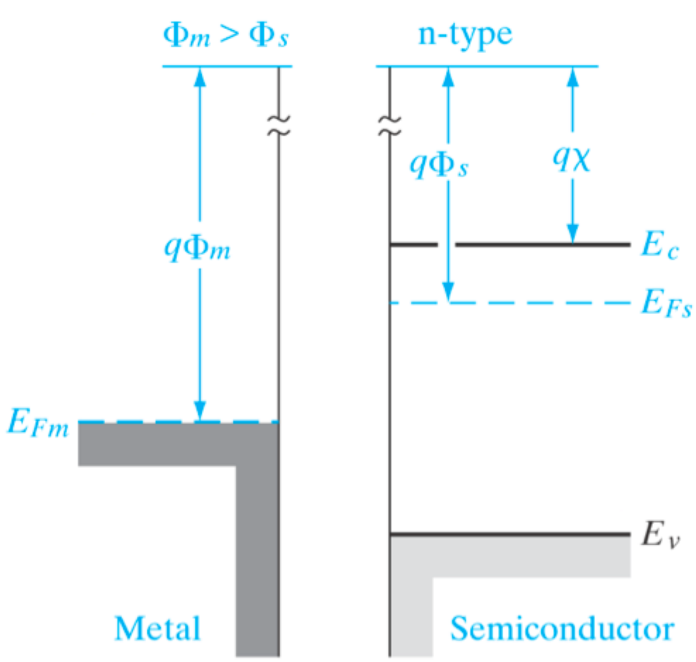
- ***<u>Image Charge:</u>*** Positive charge induced in the metal when negative charges are brought near the surface
- ***<u>Schottky Effect:</u>*** Reduction in work function when image charges are exposed to an applied electric field
- ***<u>Schottky Barrier Diode:</u>*** Rectifying contact formed from a metal-semiconductor contact

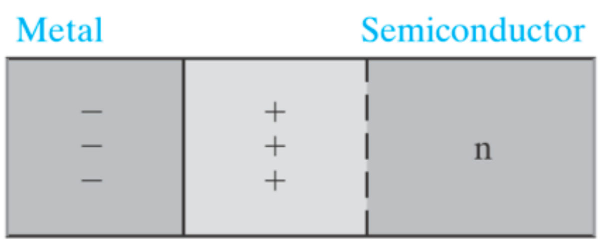


Fermi Level Alignment

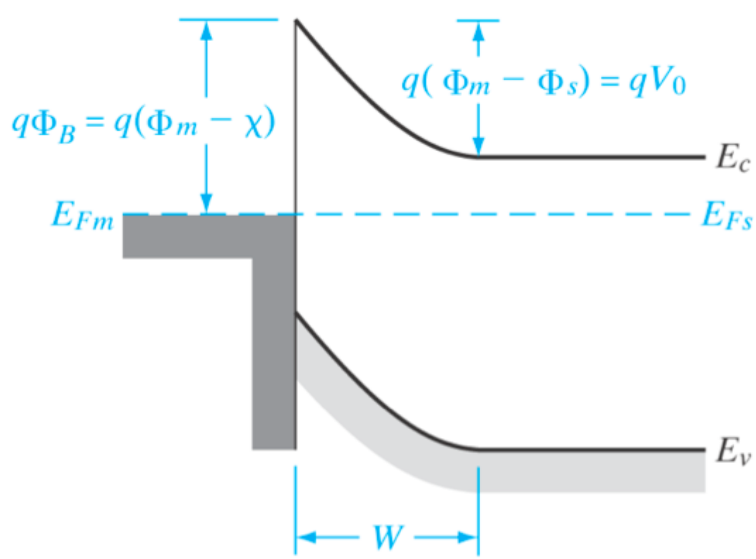
- Metal Work Function $q\Phi_m$: Energy needed to remove an electron at the Fermi level to the vacuum
- When a metal and a semiconductor are brought together, charge transfer occurs to align the Fermi levels ($q\Phi_m = q\Phi_s$)

Metal/Semiconductor Not in Contact



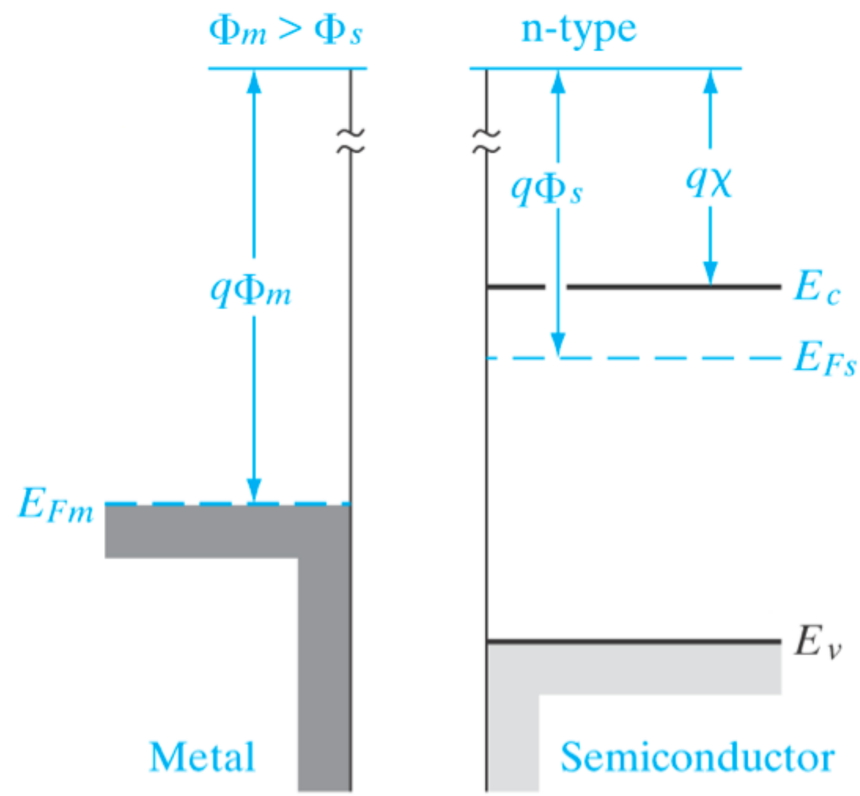


Metal/Semiconductor in Contact



Electron Affinity

- ***Electron Affinity:*** The energy from the vacuum level to the conduction band edge



Ideal Metal-Semiconductor Junctions

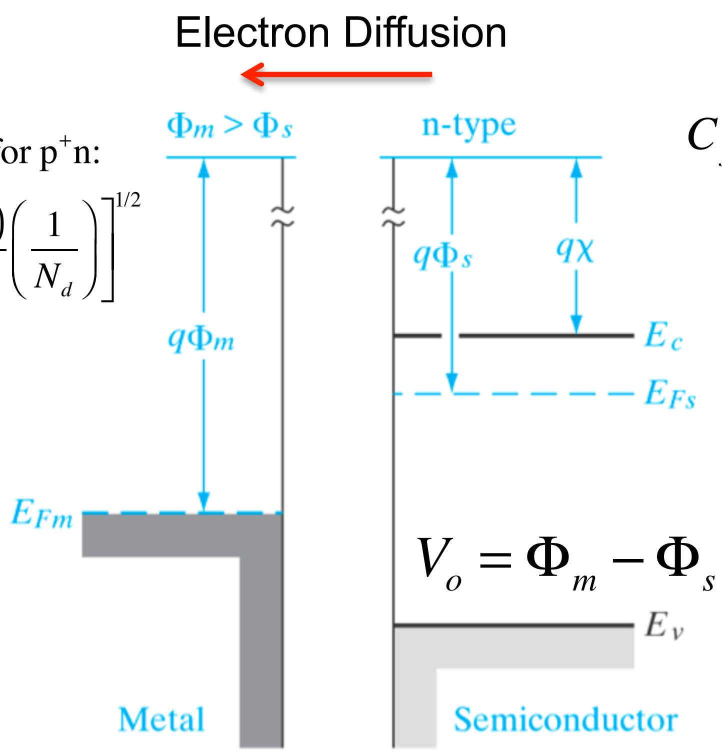
Rectifying Contacts

Case I: $q\Phi_m > q\Phi_s$, n-type Semiconductor

- Charge transfer occurs until Fermi levels align
- A depletion region is formed near the metal-semiconductor junction
- The positive charge due to uncompensated donors matches the negative charge on the metal
- Electric field and bending bands similar to p-n junctions (p^+-n approximation)

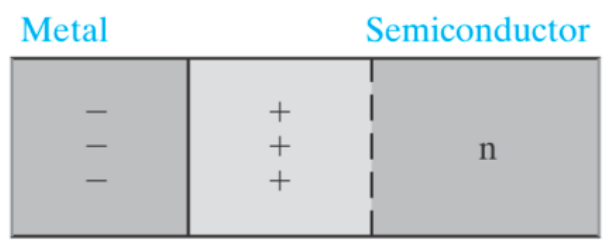
Approximation for p^+n:

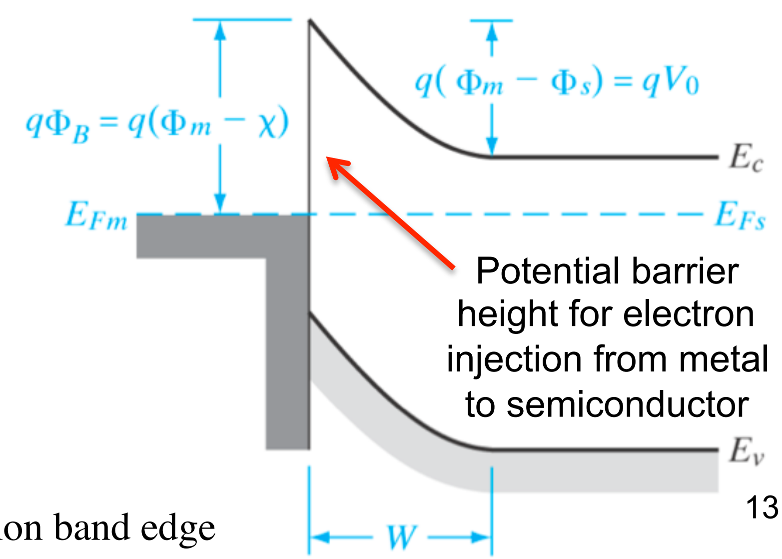
$$W \sim \left[\frac{2\varepsilon(V_0 - V)}{q}\left(\frac{1}{N_d}\right)\right]^{1/2}$$



$$V_o = \Phi_m - \Phi_s$$

$$C_j = \frac{\varepsilon_s A}{W}$$

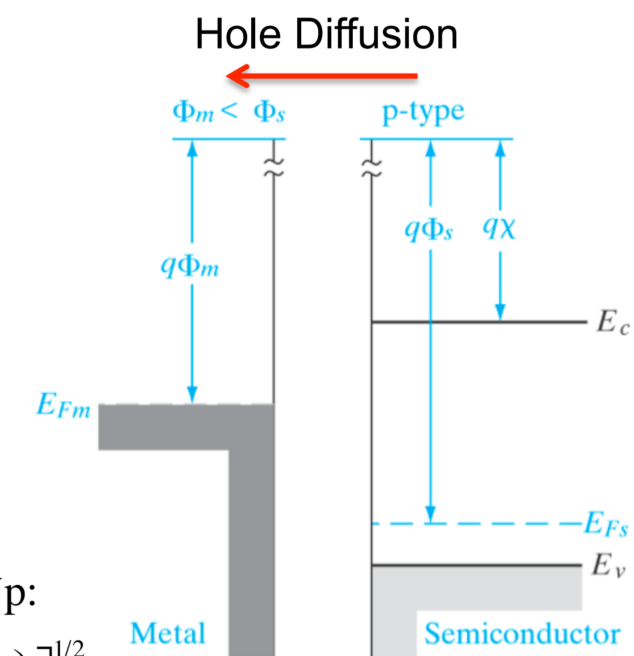


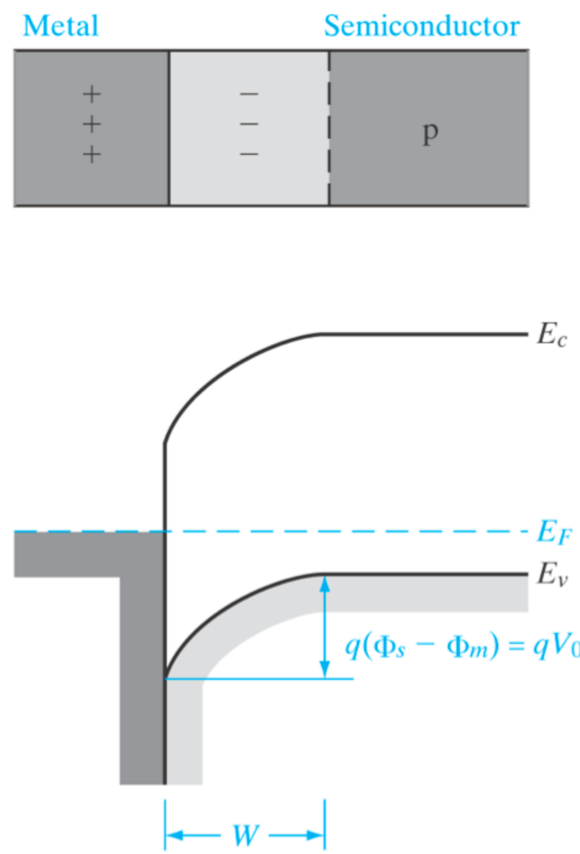


$q\chi \equiv$ electron affinity, measured from vacuum level to conduction band edge

Case II: $q\Phi_s > q\Phi_m$, p-type Semiconductor

- Charge transfer to align Fermi Levels results in a positive charge on the metal side and a negative charge on the semiconductor side
- Depletion region formed in semiconductor – ionized acceptors provide negative charge region
- Potential barrier V_o retards hole diffusion from semiconductor to metal
- Resembles n^+-p junction



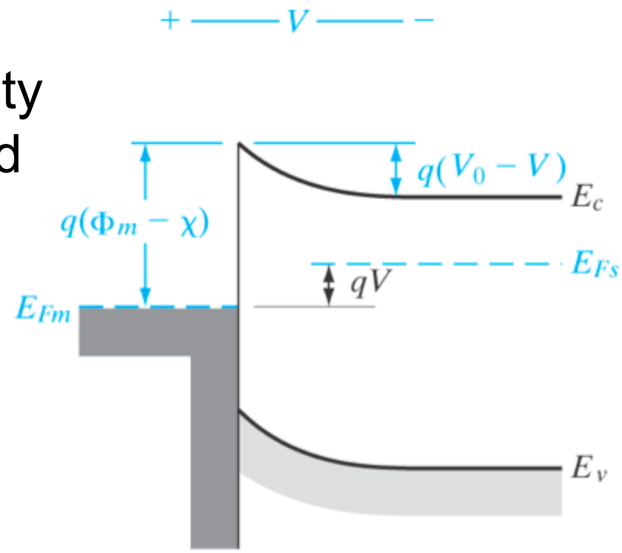


Approximation for n^+p:

$$W \sim \left[\frac{2\varepsilon(V_0 - V)}{q}\left(\frac{1}{N_a}\right)\right]^{1/2}$$

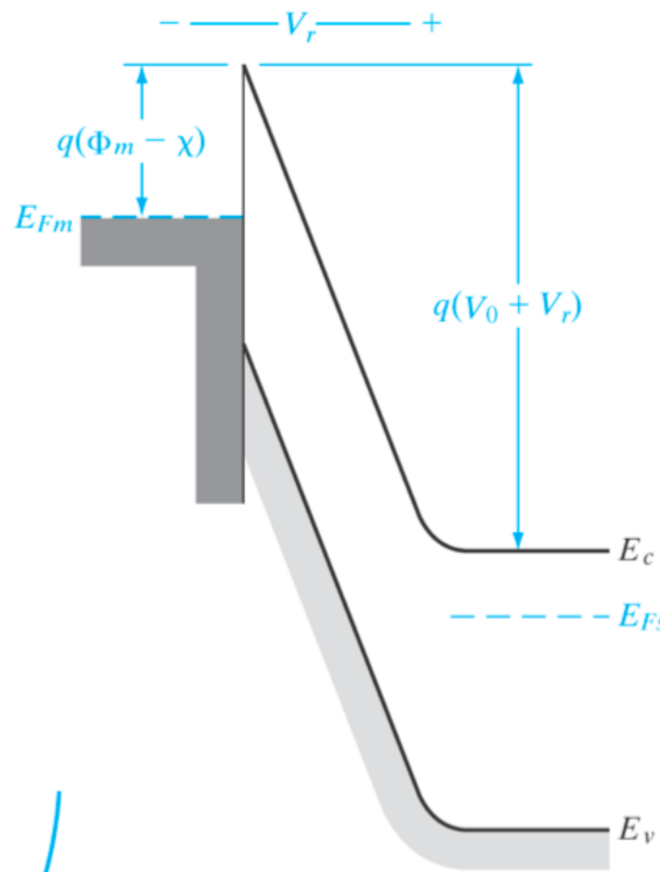
Rectifying Junctions

Reducing the barrier height causes majority carriers to be injected <u>into the metal from the semiconductor</u>



Forward bias

(a)



Reverse bias

(b)

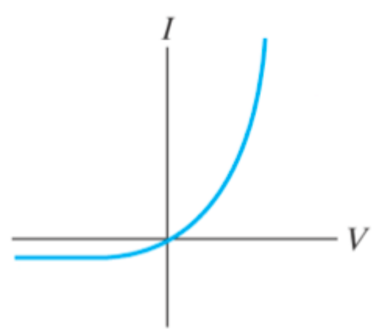
$$I = I_o(e^{qV/kT} - 1)$$

I_o is distinct from the p-n junction case:

$I_o \propto e^{-q\Phi_B/kT}$ (Boltzmann)

Φ_B is the barrier for electron injection

$\Phi_B = \Phi_m - \chi$ (Independent of applied voltage)



(c)

Forward Mode: Positive Bias to Metal

Comments:

- The forward current is due to the injection of **majority carriers** from the semiconductor into the metal
- Because there is effectively no minority carrier charge storage, there is no charge storage delay time as the device bias conditions are changed (speed advantage)

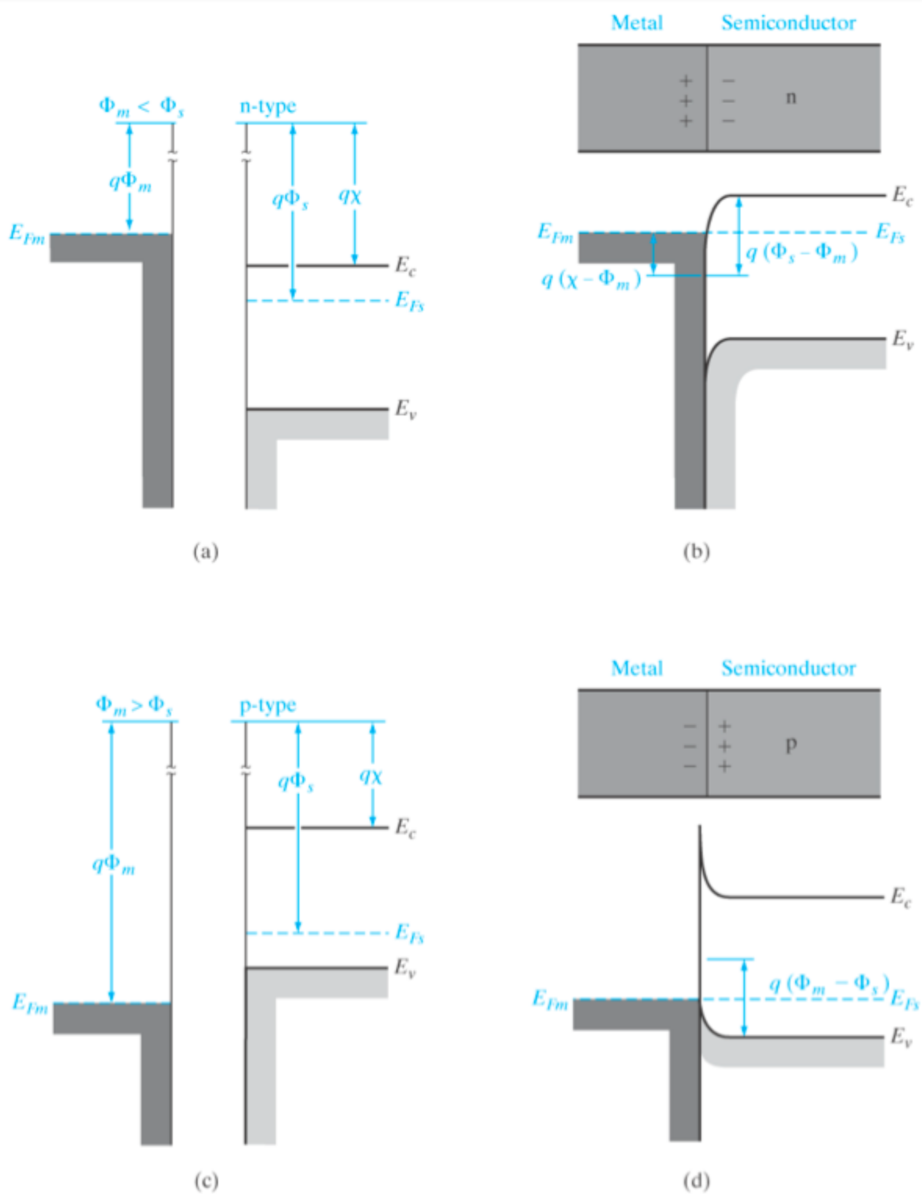
Ideal Metal-Semiconductor Junctions

Ohmic Contacts

Ohmic Contacts

Case III:
$\Phi_m < \Phi_s$
n-type

Case IV:
$\Phi_m > \Phi_s$
p-type



- Charge transfer to align Fermi levels
- Induced charged in semiconductor provided by majority carriers as opposed to ionized impurities (no depletion region)
- Practical method of forming ohmic contacts involves heavy doping of semiconductor – small depletion width allows tunneling

Summary

Ideal Metal-Semiconductor Contacts

Contact Type: Doping and Work Function

	$\Phi_m > \Phi_s$	$\Phi_s > \Phi_m$
n-type	Rectifying	Ohmic
p-type	Ohmic	Rectifying

Summary: Metal-Semiconductor Contacts

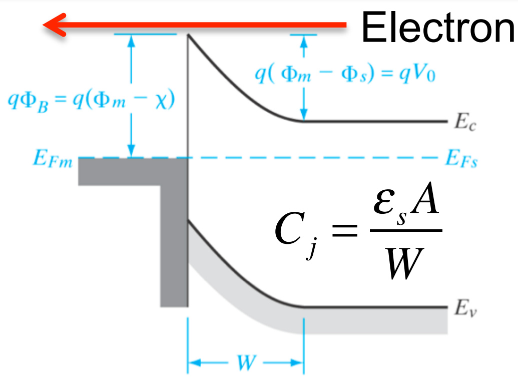
Forward Bias: Majority Carrier Injection Into Metal as Barrier is Reduced

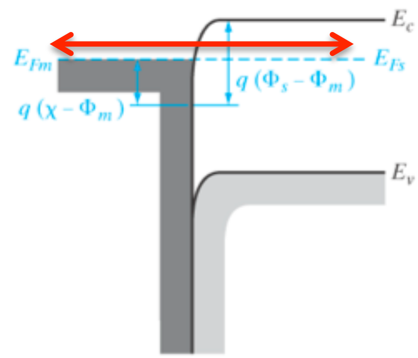
Reverse Bias: Thermionic Emission Over Barrier from Metal

$$I = I_o(e^{qV/kT} - 1)$$

$$I_o \propto e^{-q\Phi_B/kT}$$

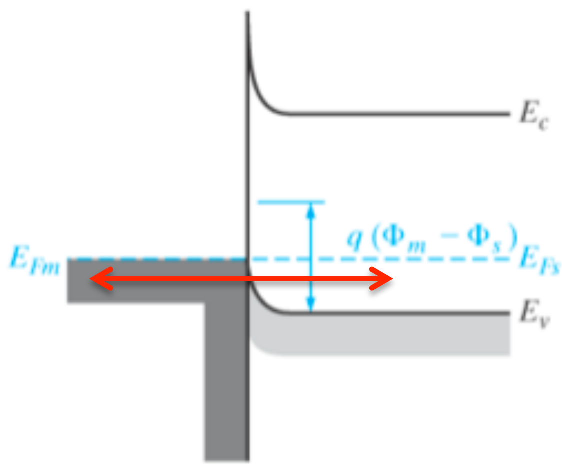
$$\Phi_B = \Phi_m - \chi$$

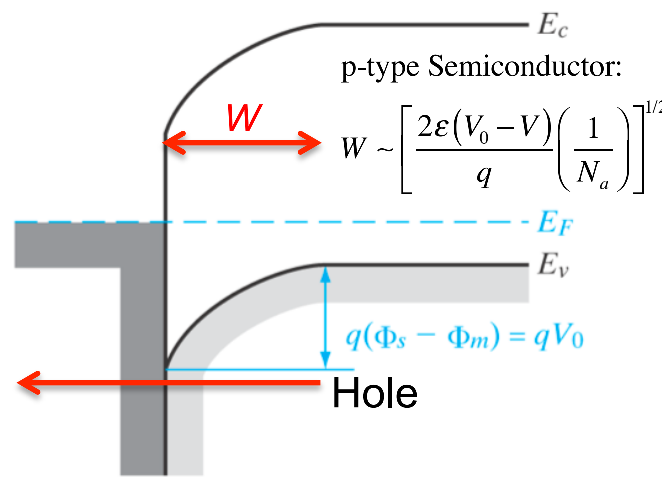




	$\Phi_m > \Phi_s$	$\Phi_s > \Phi_m$
n-type	Rectifying	Ohmic
p-type	Ohmic	Rectifying

Ohmic: Free Flow of Majority Carriers

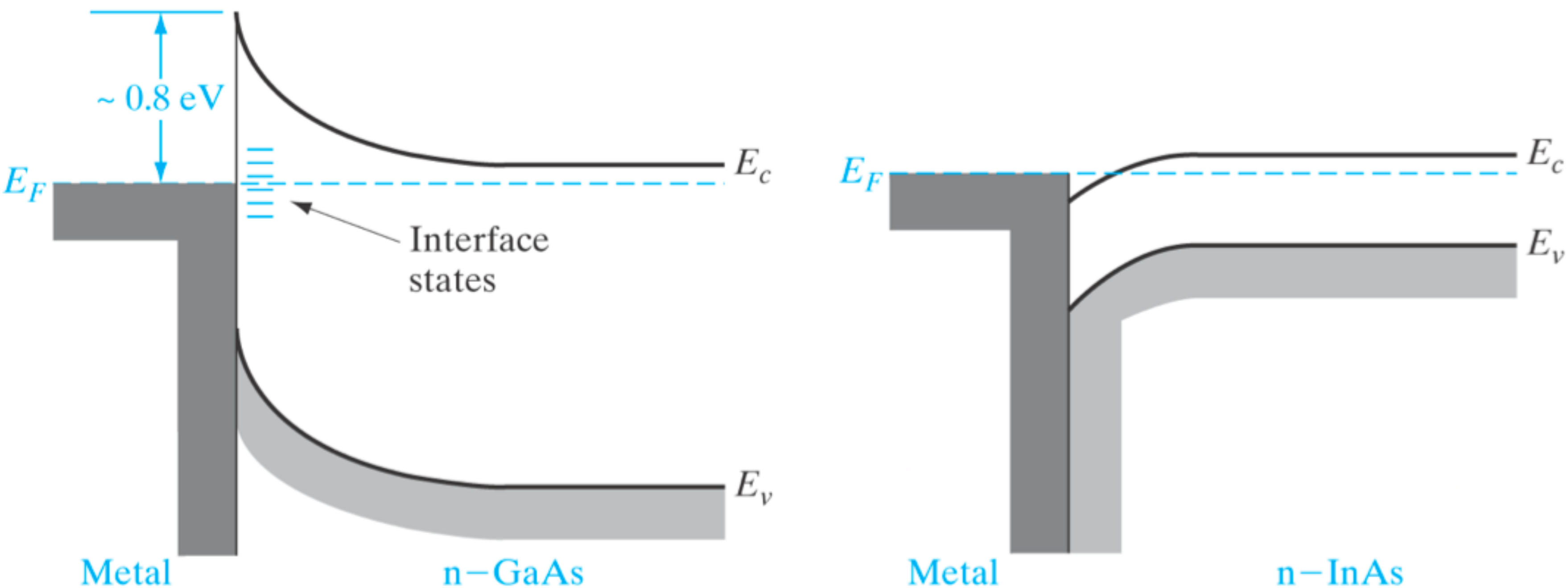




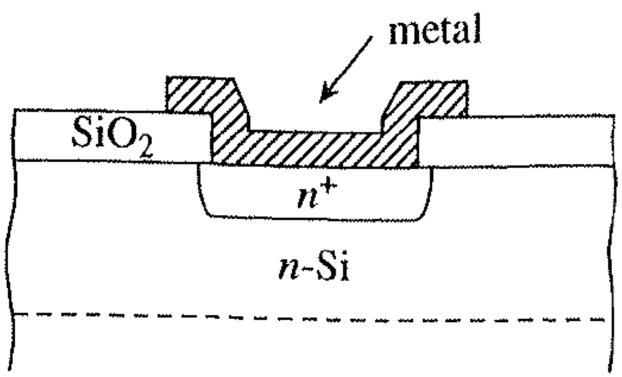
Comments on Non-Ideal Junctions

Bonus Material

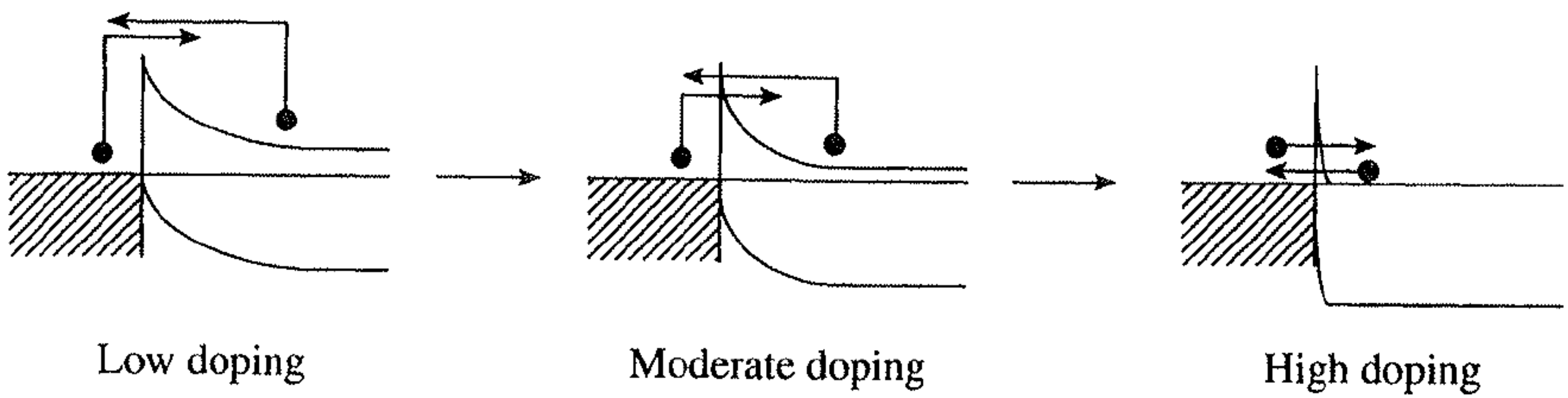
Interface States and Fermi Level Pinning



Ohmic Contacts Via Tunneling



(a)



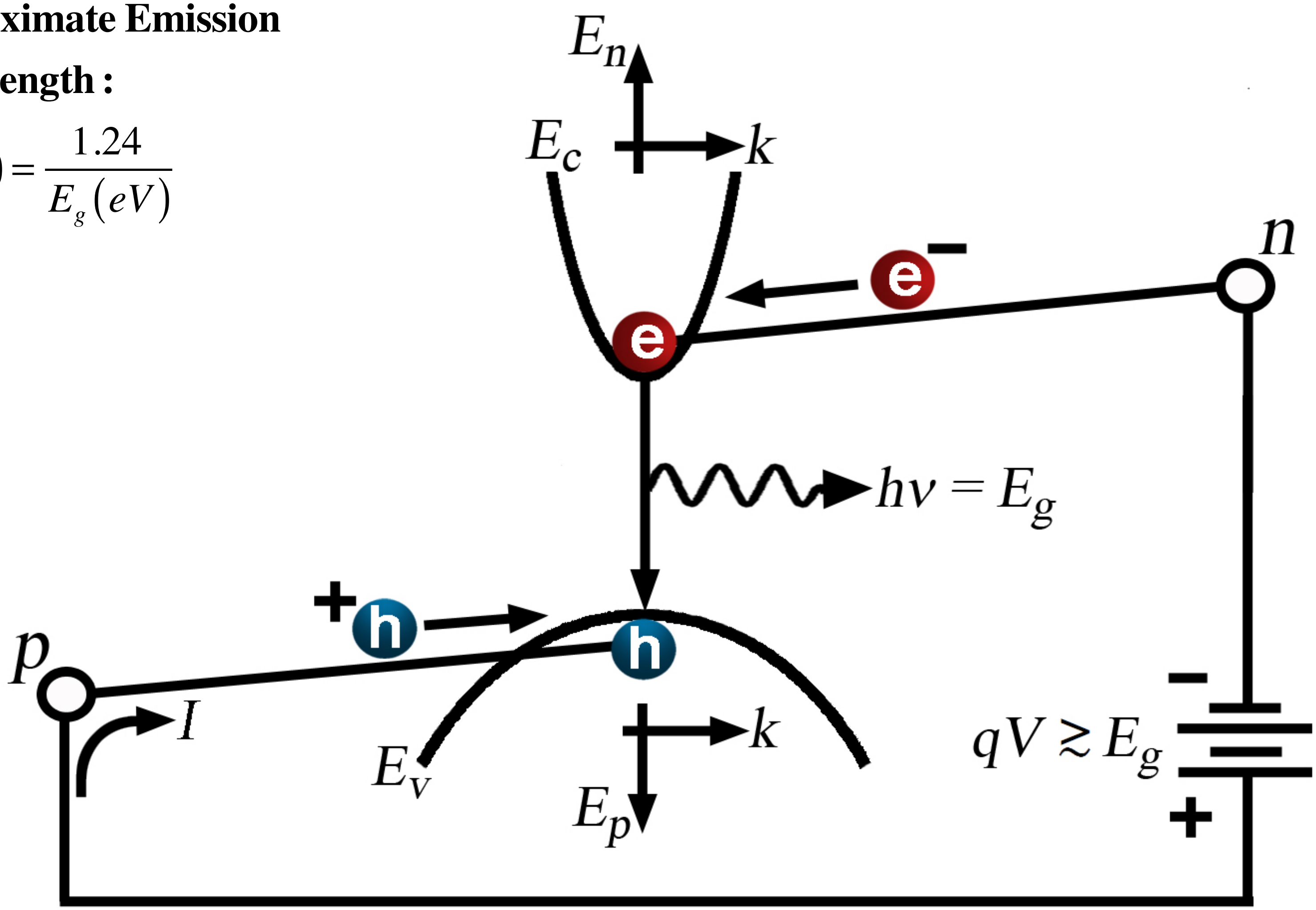
Light Emitting Diodes

Holonyak and Bardeen

The Ultimate Lamp

Approximate Emission Wavelength :

$$\lambda(\mu m) = \frac{1.24}{E_g(eV)}$$



$$\eta_{ext} = (\text{Internal Radiative Efficiency}) \times (\text{Extraction Efficiency})$$

LED: Comments and Definitions

- Injection electroluminescence: light given off by direct-gap diode under forward bias
- Photon "color" determined by bandgap
- Internal efficiency reduced by nonradiative recombination
- External efficiency reduced by photon extraction
- Optical isolator: provides complete electrical isolation by coupling a signal through an "optoelectronic pair" (light emitter – photodiode)

- Useful Expressions:

$$I = I_{dr} \exp\left[\frac{q(V - IR_s)}{kT}\right] + I_{nr} \exp\left[\frac{q(V - IR_s)}{2kT}\right]$$

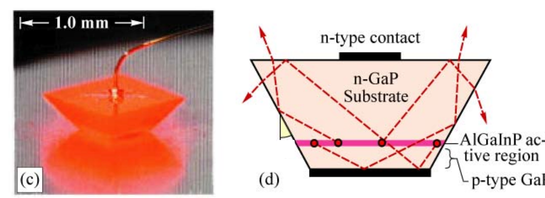
I_{dr}: diffusion radiative saturation current

I_{nr}: nonradiative recombination saturation current

R_s: device series resistance

$$\sin\theta_C = \frac{n_1}{n_2}, \ n_2 > n_1$$

n_2 incident media



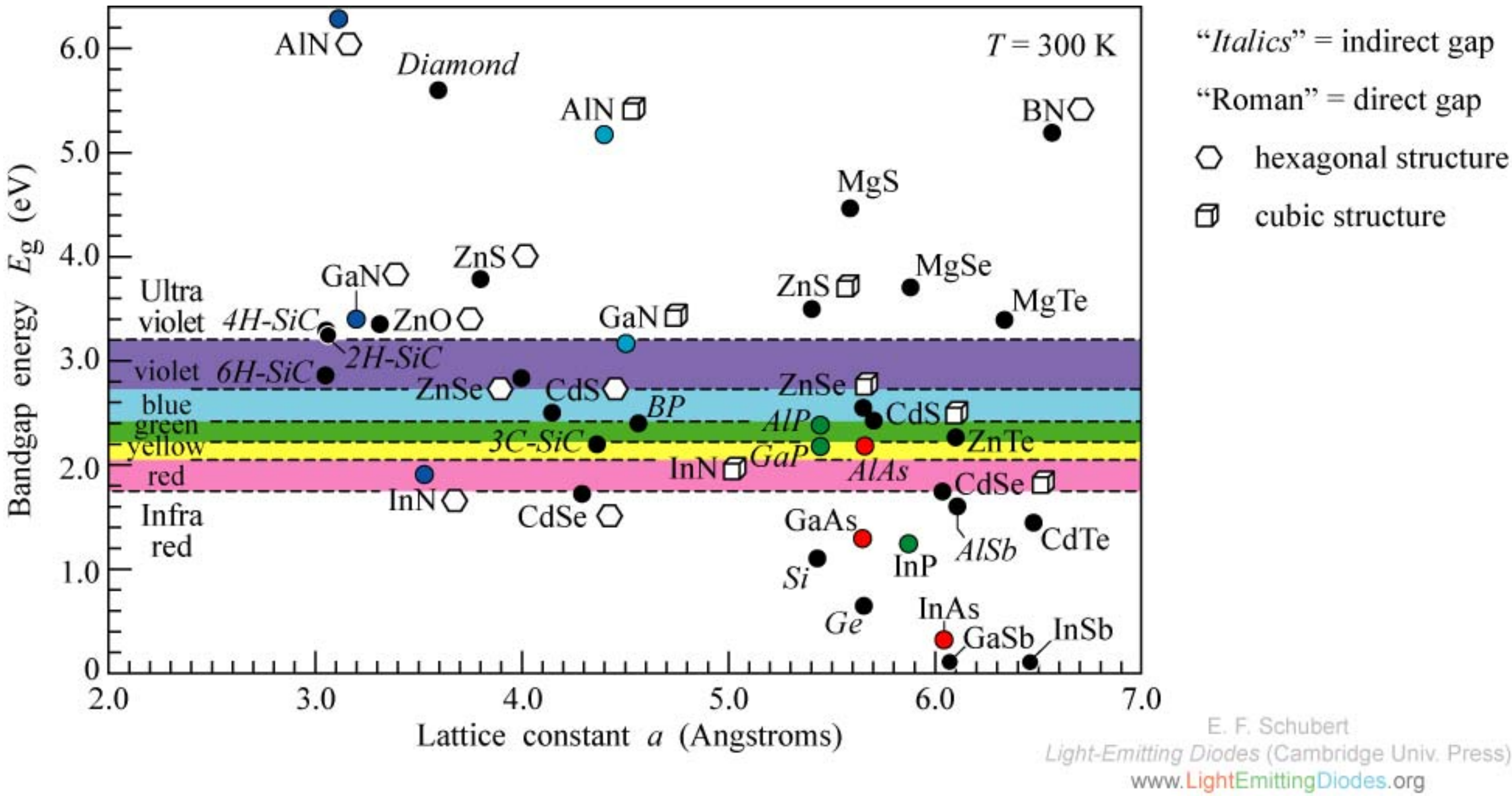
Maximum Eye Sensitivity at $\lambda = 0.555\ \mu\text{m}$

$E_g = 2.234 eV (\lambda_m = 0.555 \mu m) \Leftrightarrow$ Yellow/Green

$E_g = 1.8 eV (\lambda_g = 0.7 \mu m) \Leftrightarrow$ Red

$E_g = 2.88 eV (\lambda_g = 0.43 \mu m) \Leftrightarrow$ Blue

Bandgap and Lattice Constant of Common Semiconductors



Indirect Gap: N-Doping

Direct Gap

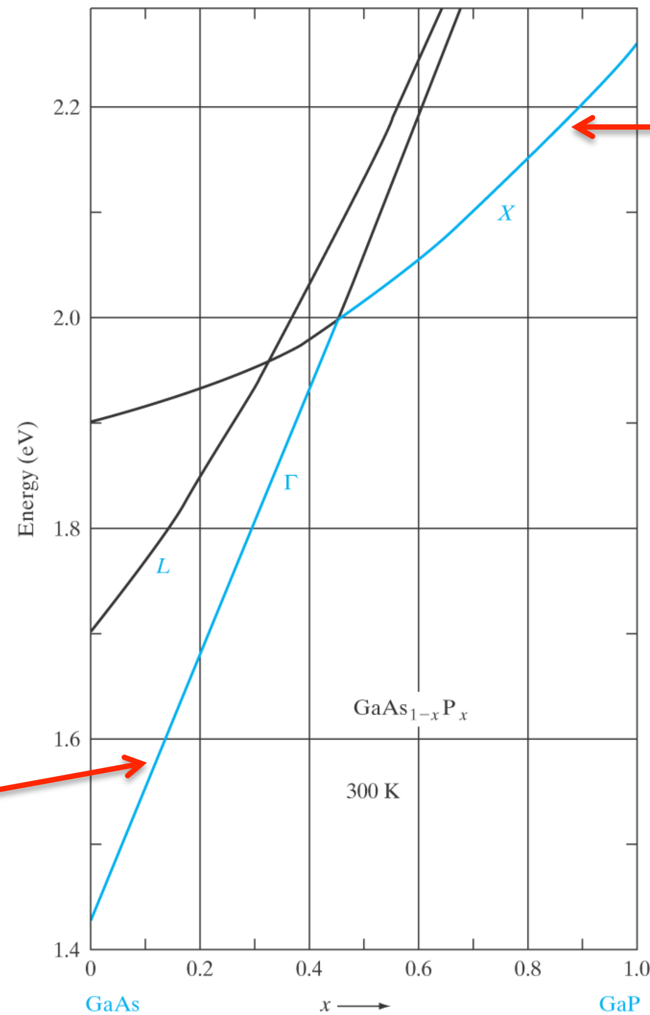
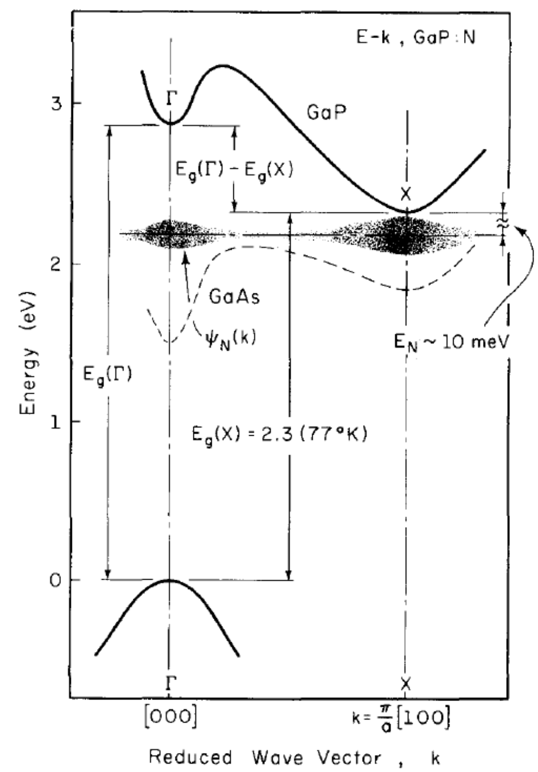


Figure 8.11

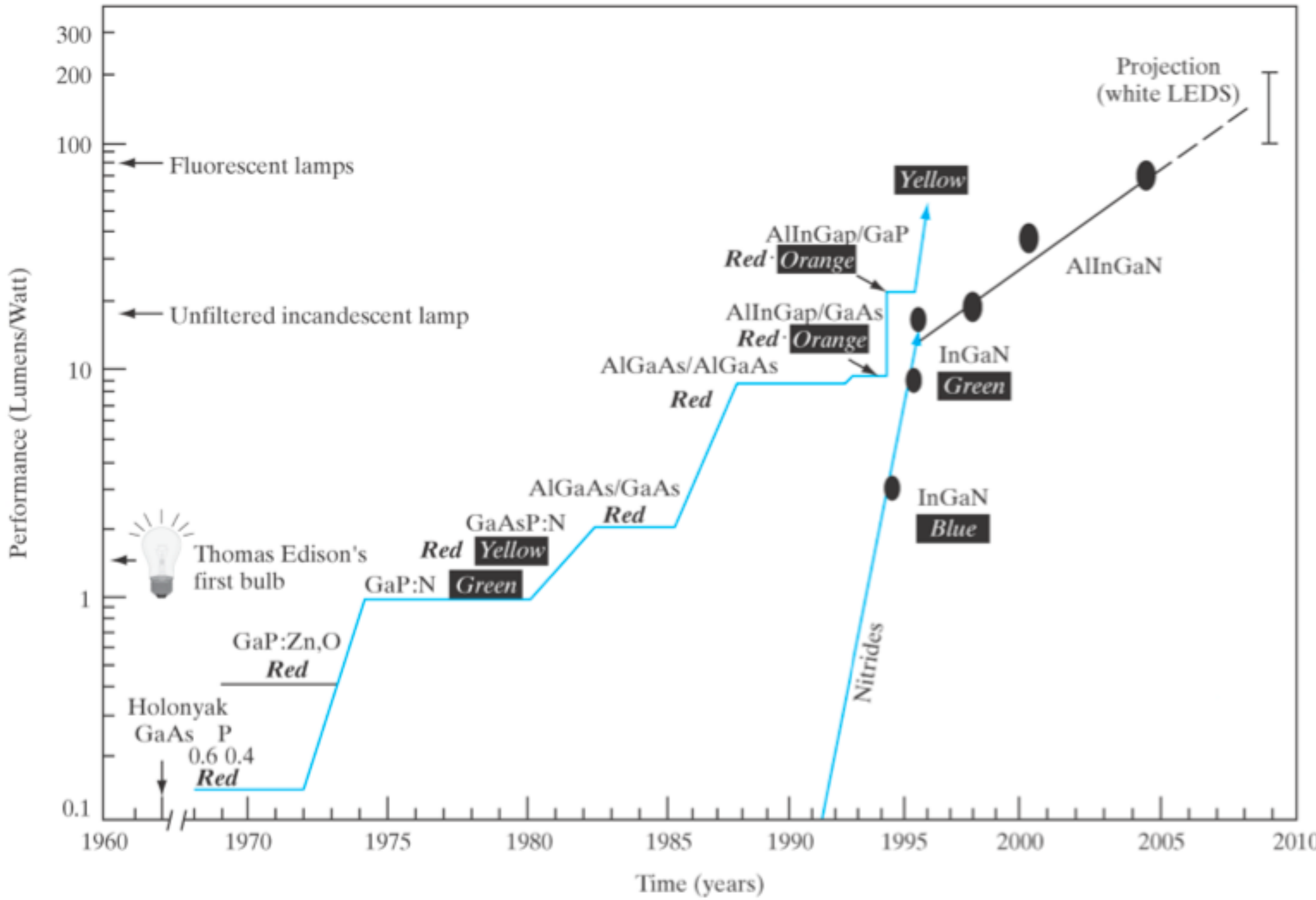
Conduction band energies as a function of alloy composition for $GaAs_{1-x}P_x$.



Holonyak, et al.,
J. Appl. Phys. **44**, 5517 (1973)

From *Solid State Electronic Devices,* Sixth Edition, by Ben G. Streetman and Sanjay Kumar Banerjee.
ISBN 0-13-149726-X.

The Alloy Road



Fiber Optic Communications

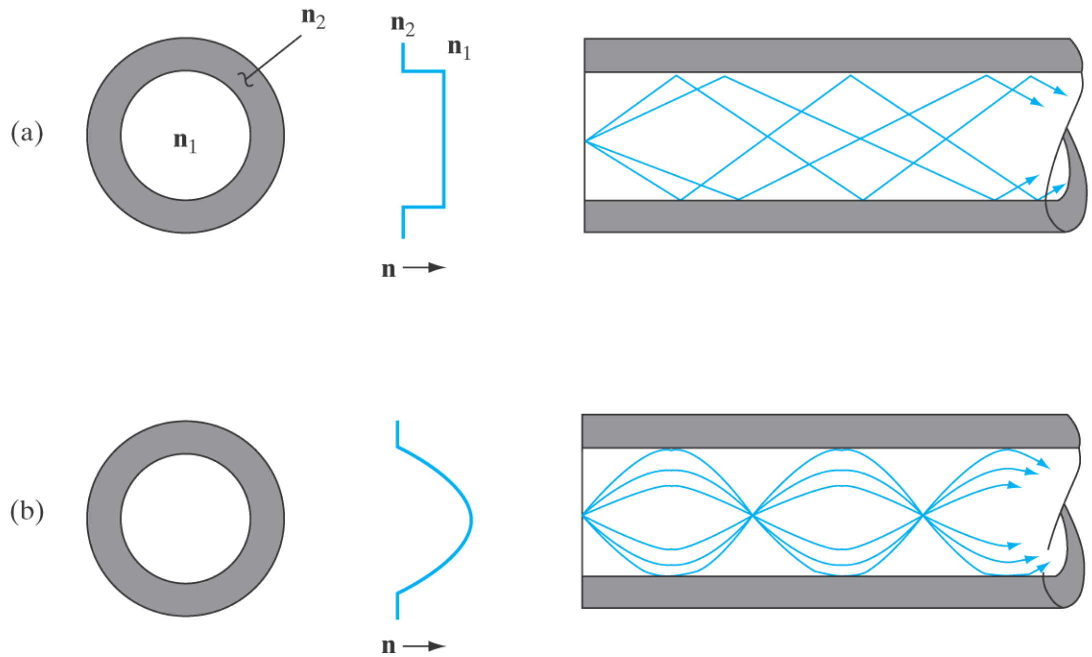
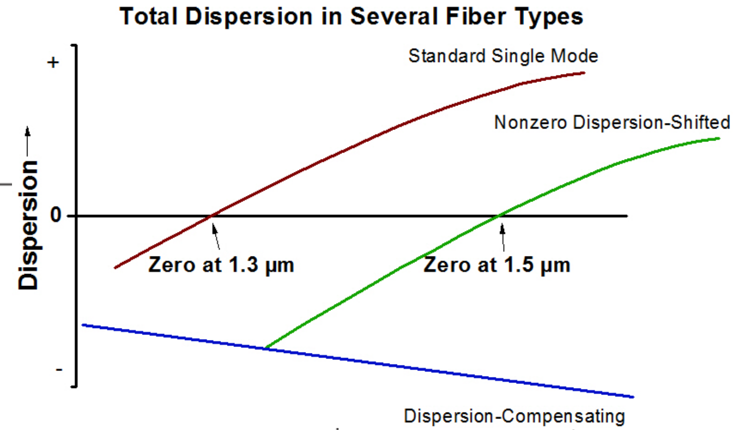


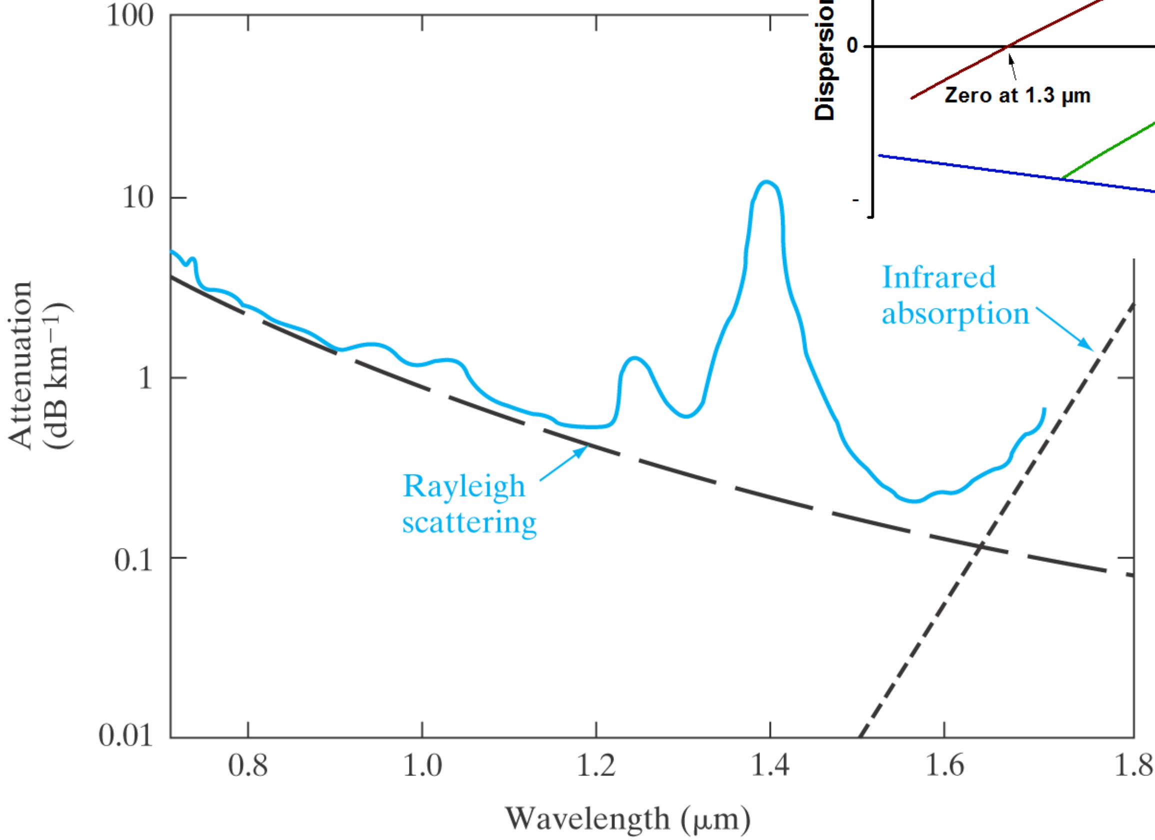
Figure 8.12

Two examples of multimode fibers: (a) *a step index* having a core with a slightly larger refractive index **n**; (b) *a graded index* having, in this case, a parabolic grading of **n** in the core. The figure illustrates the cross section (left) of the fiber, its index-of-refraction profile (center), and typical mode patterns (right).

SMF Absorption and Dispersion



from Thorlabs



$$I(x) = I_0 e^{-\alpha x}$$

Figure 8.13

Typical plot of attenuation coefficient α vs. wavelength λ for a fused silica optical fiber. Peaks are due primarily to OH^- impurities.

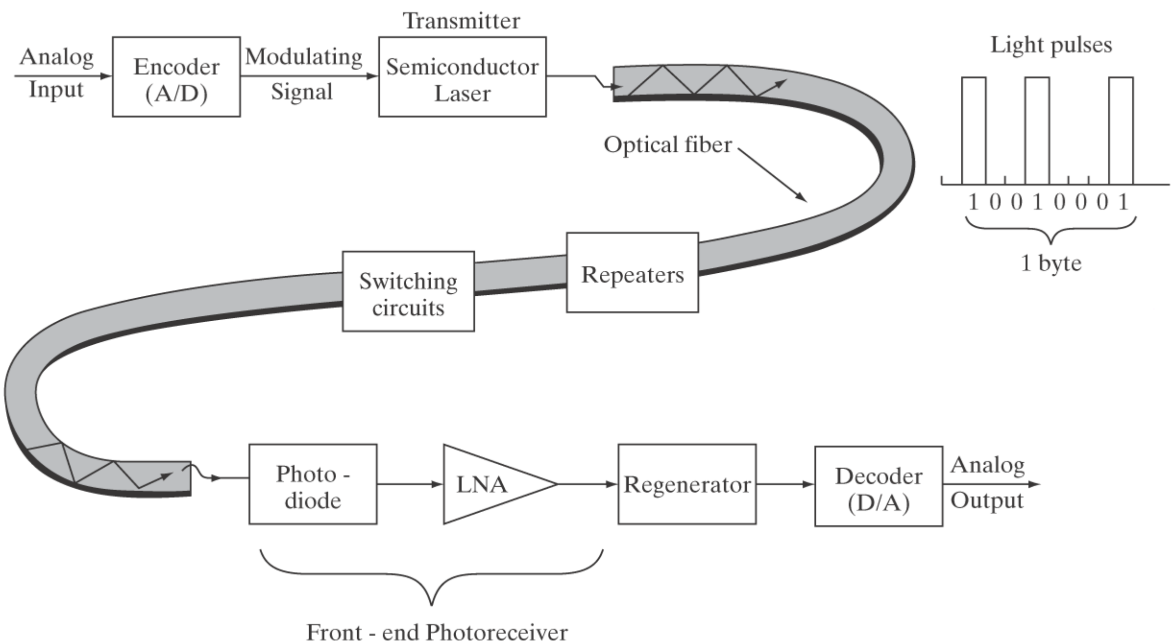


Figure 8.14a

Schematic of a fiber-optic communication system illustrating the transmission of analog signals, such as those in telephony or TV. After the signal is converted to a digital electrical signal, it is used to modulate the laser light output as light pulses that are transmitted down the fiber, with periodic amplification of the signal with repeaters to compensate for fiber loss. Switching circuits route signals appropriately. After the optical signal is transformed to an electrical output by a photodetector and a low-noise preamplifier (LNA), it is converted to an analog signal, once distortions of the digital signals due to propagation through the fiber have been corrected with the use of a "regenerator."

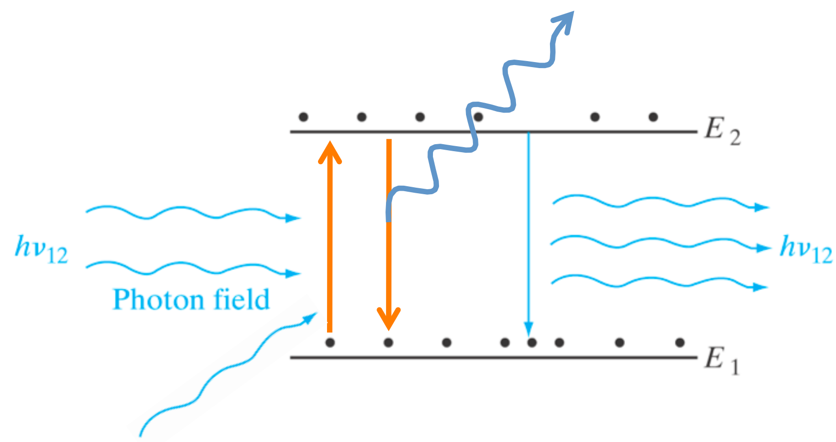
Lasers

Transitions in a 2-State System

LASER: Light Amplification through Stimulated Emission of Radiation

3 EHP-Photon Processes:

- ***Spontaneous Emission:*** Random transition from E_2 to E_1
- ***Absorption:*** Transition from E_1 to E_2 caused by interaction with and annihilation of a photon
- ***Stimulated Emission:*** Transition caused by presence of photon field
  - Stimulated photons have the same energy and phase as the stimulating photon field (monochromatic, coherent)



Two State System

Consider a two state system with the following properties:

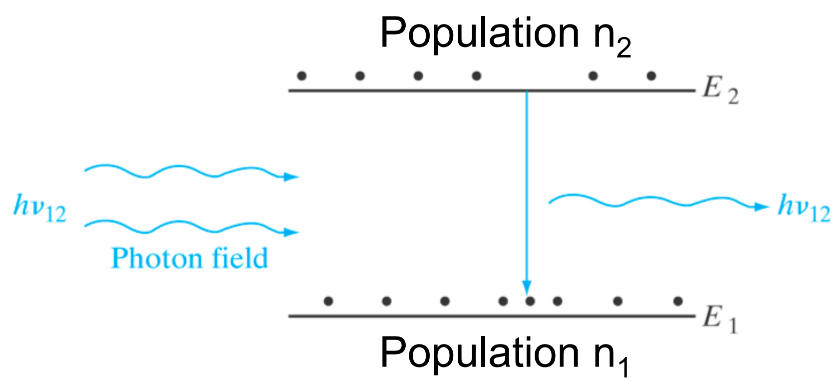
An upper state energy E_2

An upper state electron density (population) n_2

A lower state energy E_1

A lower state electron density (population) n_1

A photon energy $E_2 - E_1 = h\nu_{12}$ between the levels



From Boltzmann Statistics,

at **Thermal Equilibrium :**

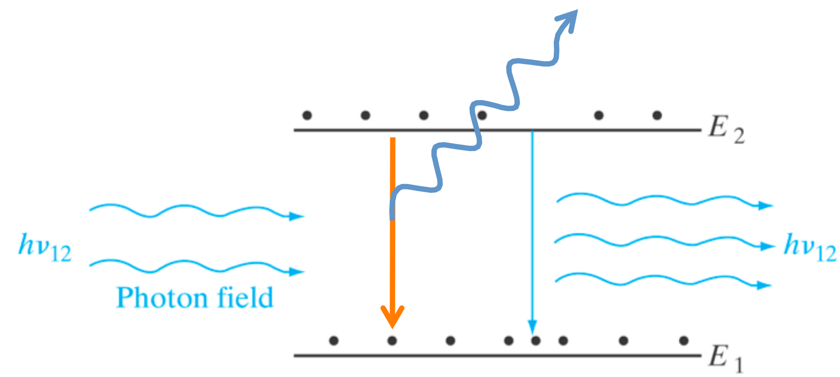
$$\frac{n_2}{n_1} = e^{-(E_2-E_1)/kT} = e^{-h\nu_{12}/kT}$$

so in ***thermal equilibrium*** $n_2 \ll n_1$

What would happen if T were negative?

Spontaneous Emission

The rate of spontaneous emission is proportional only to the number of electrons in the upper state:



$$R_{spon} = -\left.\frac{dn_2}{dt}\right|_{spon} = A_{21} n_2$$

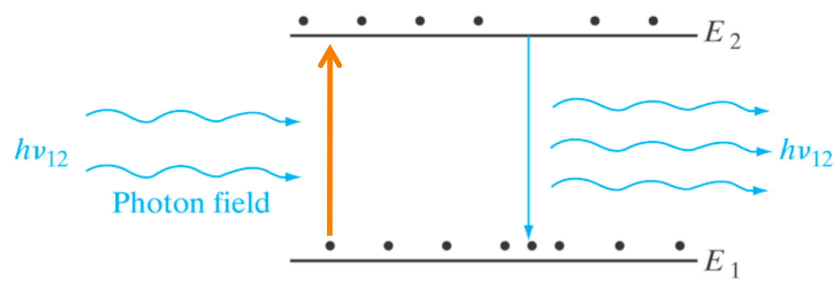
Spontaneous decay time constant: $\tau_{spon} = \left(A_{21}\right)^{-1}$

Note: Don't confuse the two-state system with band-to-band processes discussed earlier where we found:

$R_n = R_p = \alpha_r np$

Absorption

The rate of absorption is proportional to the number of electrons in the lower state and the energy density.



Where:

$R_{abs} \equiv$ Rate of absorption

$\rho(\nu_{12}) \equiv$ System with energy density

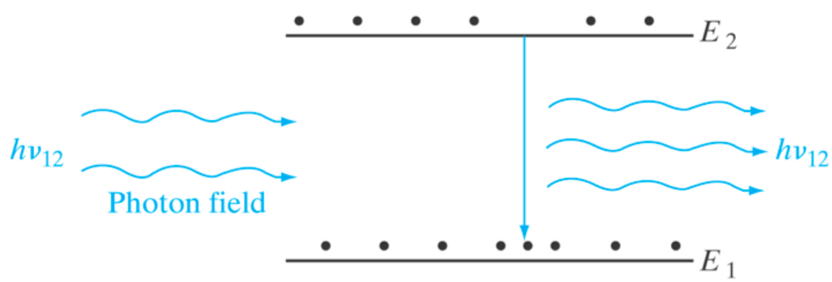
$n_1 \equiv$ Electron population in the lower level

The rate of absorption is given by:

$$R_{abs} = \left.\frac{dn_2}{dt}\right|_{abs} = -\left.\frac{dn_1}{dt}\right|_{abs} = B_{12} n_1 \rho(\nu_{12})$$

Stimulated Emission

The rate of stimulated emission is proportional to the number of electrons in upper level and the energy density.



Where:

$R_{stim} \equiv$ Rate of stimulated emission

$\rho(\nu_{12}) \equiv$ System with energy density

$n_2 \equiv$ Electron population in the upper level

The rate of stimulated emission is given by:

$$R_{stim} = \left.\frac{dn_1}{dt}\right| = -\left.\frac{dn_2}{dt}\right| = B_{21} n_2 \rho(\nu_{12})$$

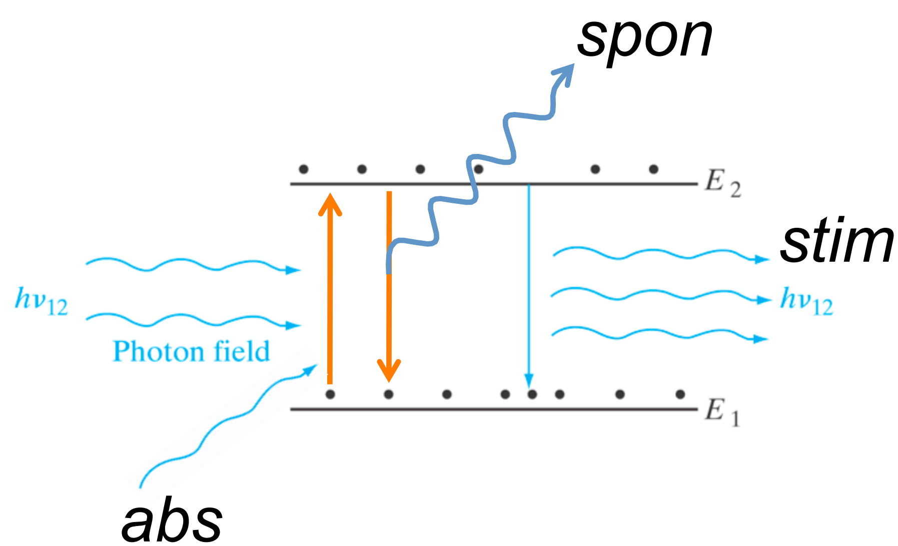
Steady State Condition

For :

$$R_{stim} = B_{21} n_2 \rho(\nu_{12})$$

$$R_{abs} = B_{12} n_1 \rho(\nu_{12})$$

$$R_{spon} = A_{21} n_2$$



In steady state, the emission rates must balance the absorption rate:

$$\left.\frac{dn_2}{dt}\right|_{abs} + \left.\frac{dn_2}{dt}\right|_{spon} + \left.\frac{dn_2}{dt}\right|_{stim} = 0 \quad \text{or}$$

$$B_{12} n_1 \rho(\nu_{12}) = A_{21} n_2 + B_{21} n_2 \rho(\nu_{12})$$

$$[\text{Absorption}] = [\text{Spontaneous Emission}] + [\text{Stimulated Emission}]$$

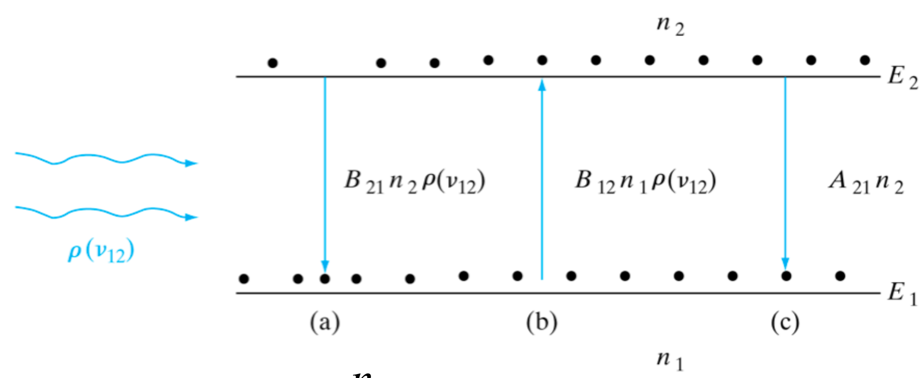
B_{12}, A_{21}, and B_{21} are the Einstein Coefficients

In steady state, the absorption is the sum of spontaneous and stimulated emission

Conditions for Lasing

$$\frac{\text{Stimulated emission rate}}{\text{Spontaneous emission rate}} = \frac{B_{21} n_2 \rho(\nu_{12})}{A_{21} n_2} = \frac{B_{21}}{A_{21}} \rho(\nu_{12})$$

A large photon field energy density enhances the stimulated emission rate (optical resonant cavity).



$$\frac{\text{Stimulated emission rate}}{\text{Absorption rate}} = \frac{B_{21} n_2 \rho(\nu_{12})}{B_{12} n_1 \rho(\nu_{12})} = \frac{B_{21}}{B_{12}} \frac{n_2}{n_1}$$

For stimulated emission to exceed absorption, $n_2 > n_1$

Population Inversion needed for stimulated emission to exceed absorption ("***negative temperature***" concept).

$$\frac{n_2}{n_1} = e^{-(E_2 - E_1)/kT} = e^{-h\nu_{12}/kT}$$

if $n_2 > n_1$ then T is "negative"

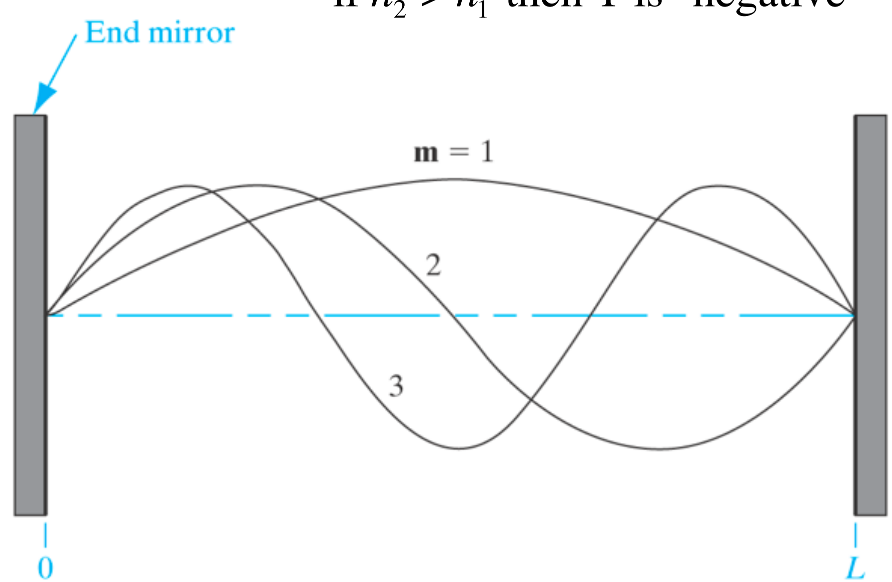
Optical Resonant Cavity: Fabry-Perot Modes

$$L = m\left(\frac{\lambda}{2}\right)$$

λ is the wavelength in the cavity. For a refractive index n:

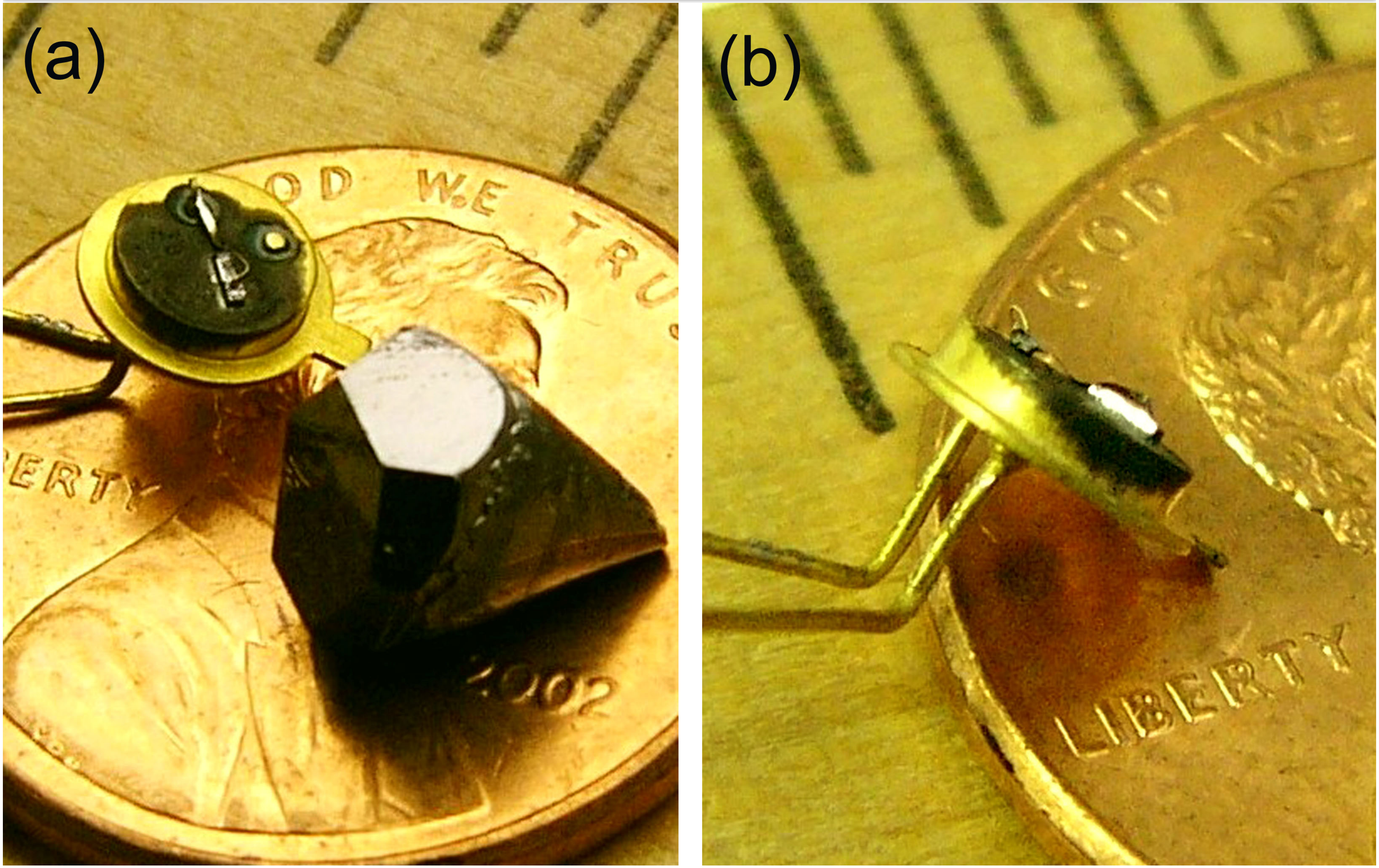
$$\lambda = \frac{\lambda_o}{n}$$

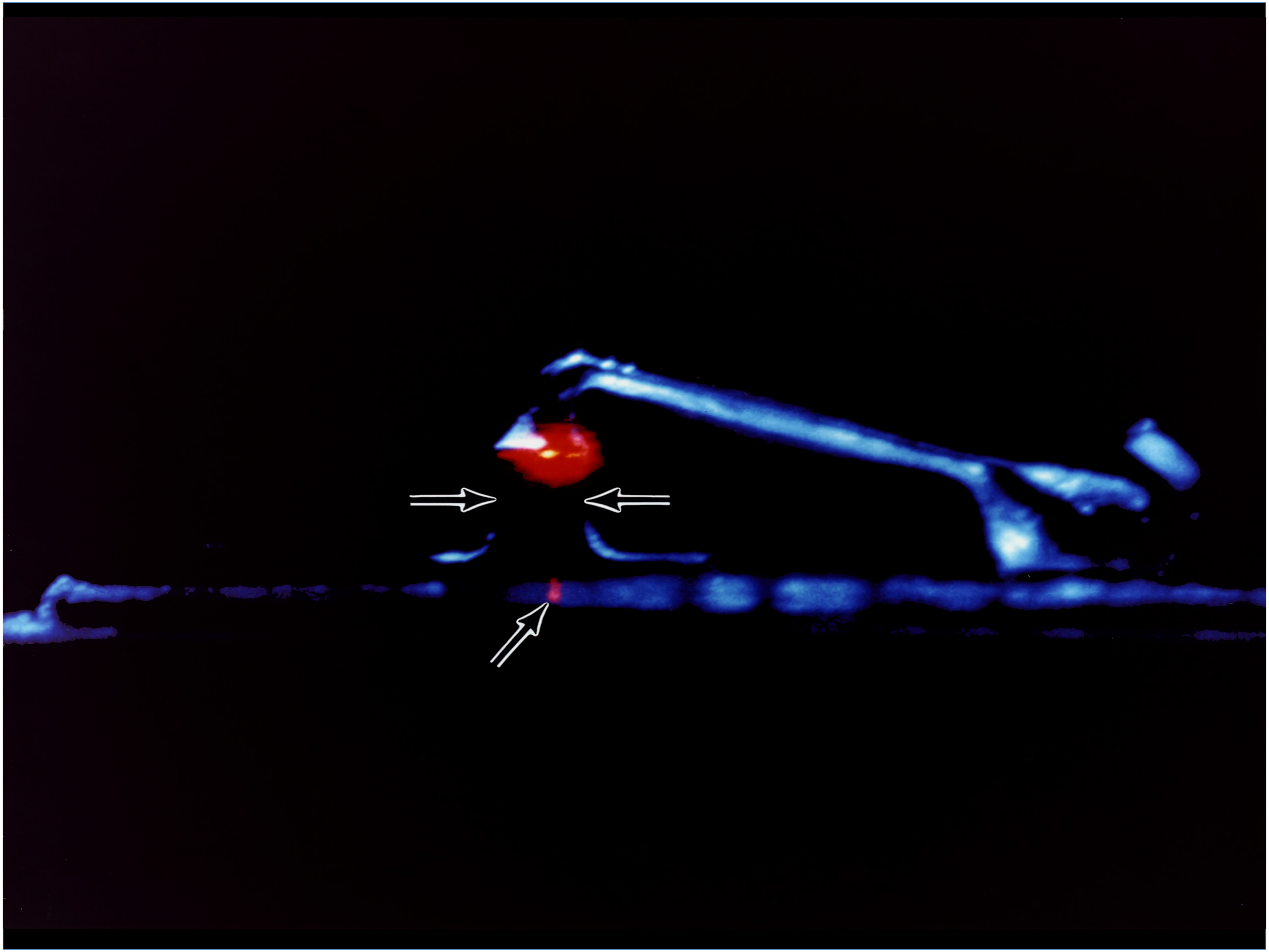
where λ_o is the wavelength in free space.



Semiconductor Lasers

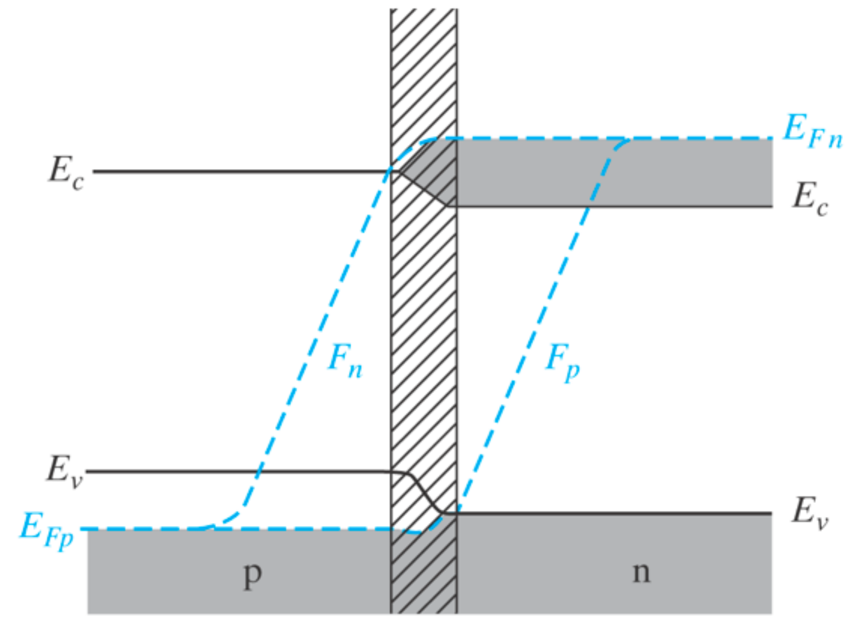
The First GaAsP Diode Laser





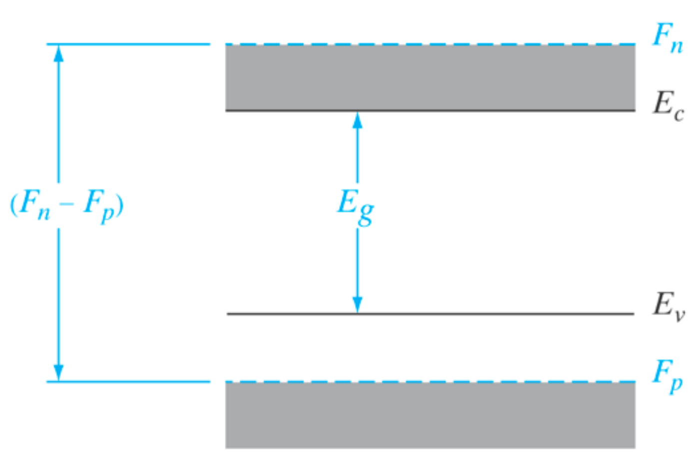
Junction Under Large Bias

- If the bias is such that electrons and holes are injected into and across the transition region in high concentration, an ***inversion region*** is created
- The population inversion is described using quasi-Fermi levels
- The separation of the quasi-Fermi levels is a measure of the population inversion
- Direct bandgap material required



$$n = N_c e^{-(E_c - F_n)/kT} = n_i e^{(F_n - E_i)/kT}$$

$$p = N_v e^{-(F_p - E_v)/kT} = n_i e^{(E_i - F_p)/kT}$$



Lasing Condition (Population Inversion):

$\left(F_n - F_p\right) > h\nu$ or, for band-edge transitions

$\left(F_n - F_p\right) > E_g$

Inversion Region Variation with Bias

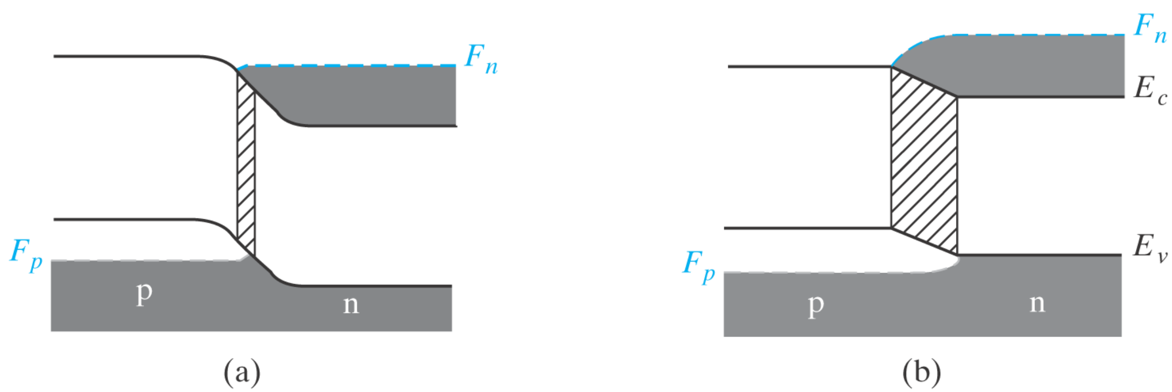
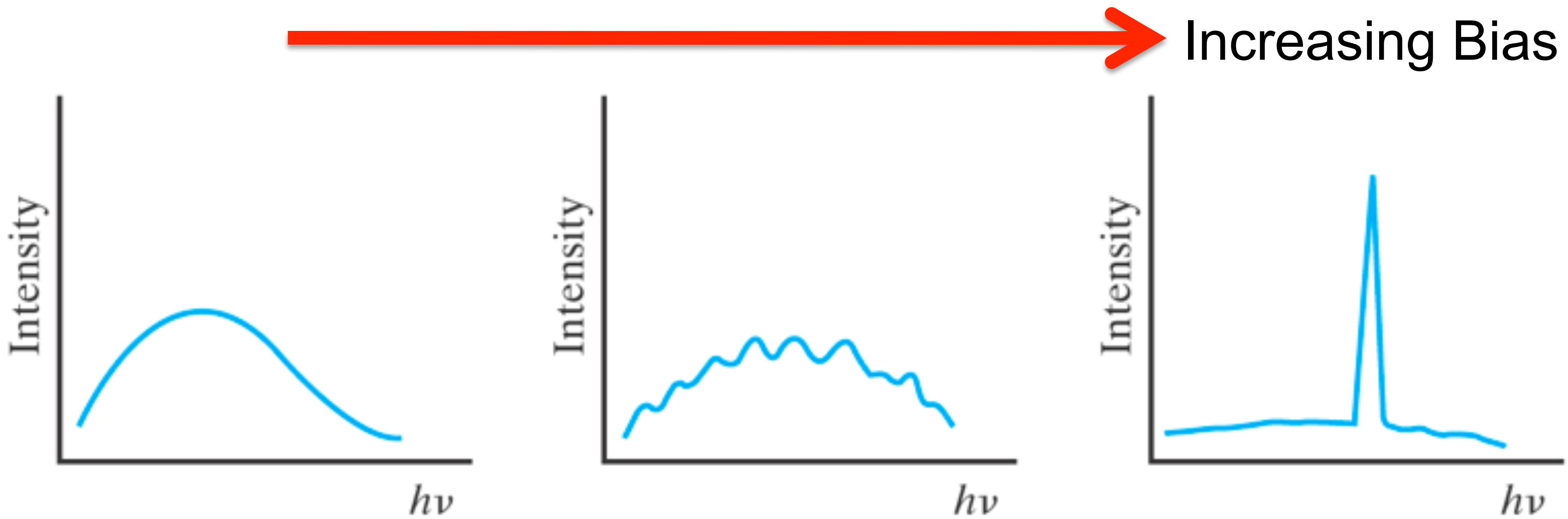


Figure 8.20

Variation of the inversion- region width with forward bias: $V(a) < V(b)$.

Laser Mode Spacing



$$L = m\left(\frac{\lambda_o}{2n}\right) \text{ so } m = \frac{2Ln}{\lambda_o} \text{ and } \frac{dm}{d\lambda_o} = -\frac{2Ln}{\lambda_o^2} + \frac{2L}{\lambda_o}\frac{dn}{d\lambda_o}$$

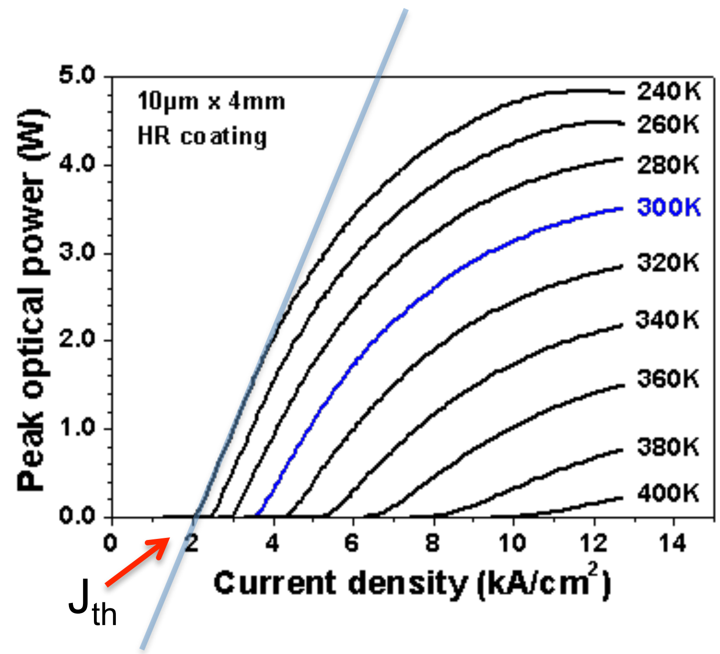
Since m is an integer:

$$\frac{\Delta m}{\Delta\lambda_o} = -\frac{2Ln}{\lambda_o^2} + \frac{2L}{\lambda_o}\frac{dn}{d\lambda_o} \text{ and } -\Delta\lambda_o = \frac{\lambda_o^2}{2Ln}\left(1 - \frac{\lambda_o}{n}\frac{dn}{d\lambda_o}\right)^{-1}\Delta m$$

Setting $\Delta m = -1$ will allow calculation of the mode spacing

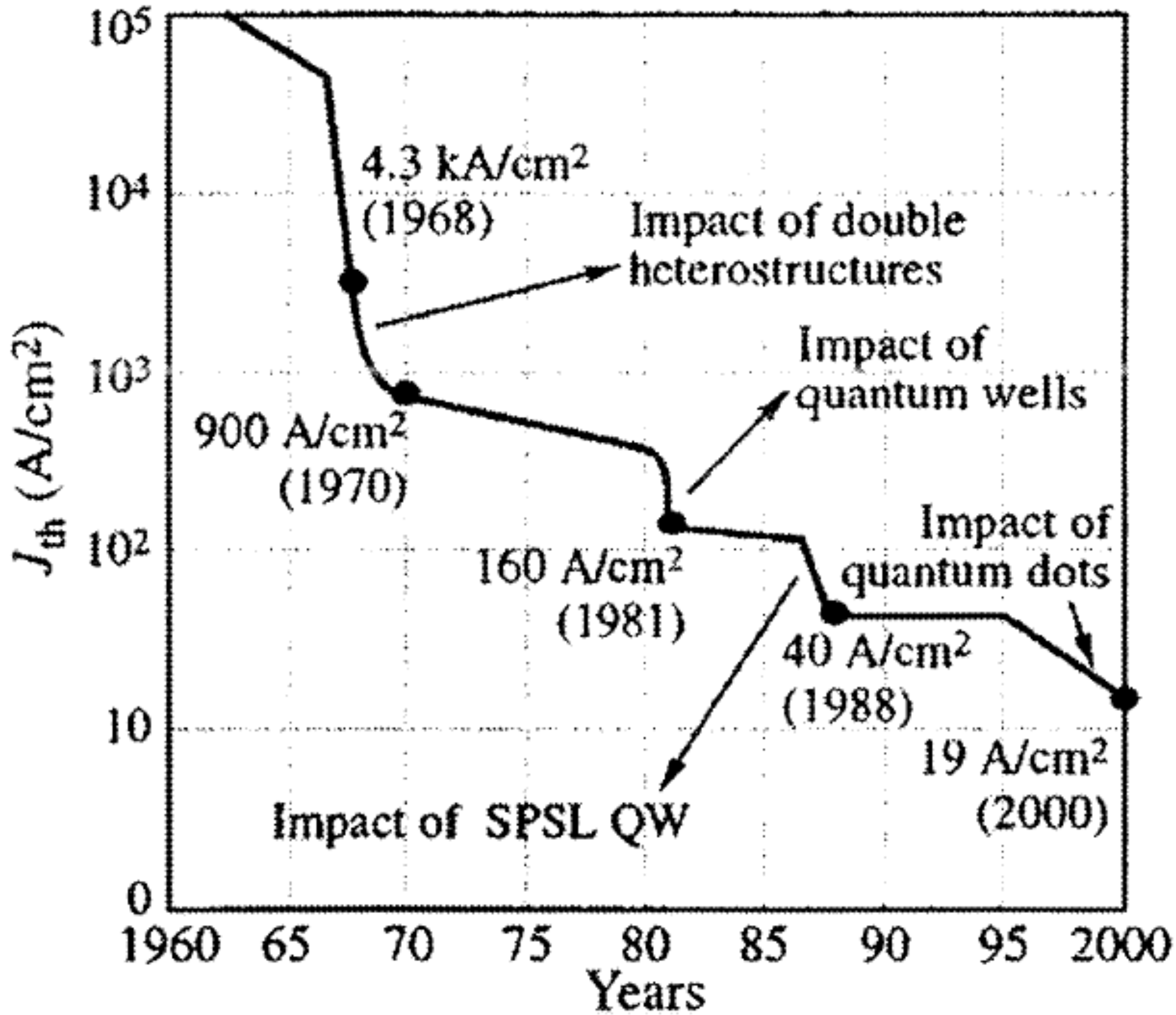
Key Figures of Merit

- ***Threshold Current:*** The current at which lasing action begins
  - The point where the L-I curve intercepts the "y" axis (0 power)
- ***Differential Quantum Efficiency:*** A measure of the number photons emitted per "electron"
  - Related to the slope of the L-I Curve



L-I curve from: http://ldsd.group.shef.ac.uk/midir/qcl.php

Technology Advances in Laser Diodes



Laser Fabrication: Basic

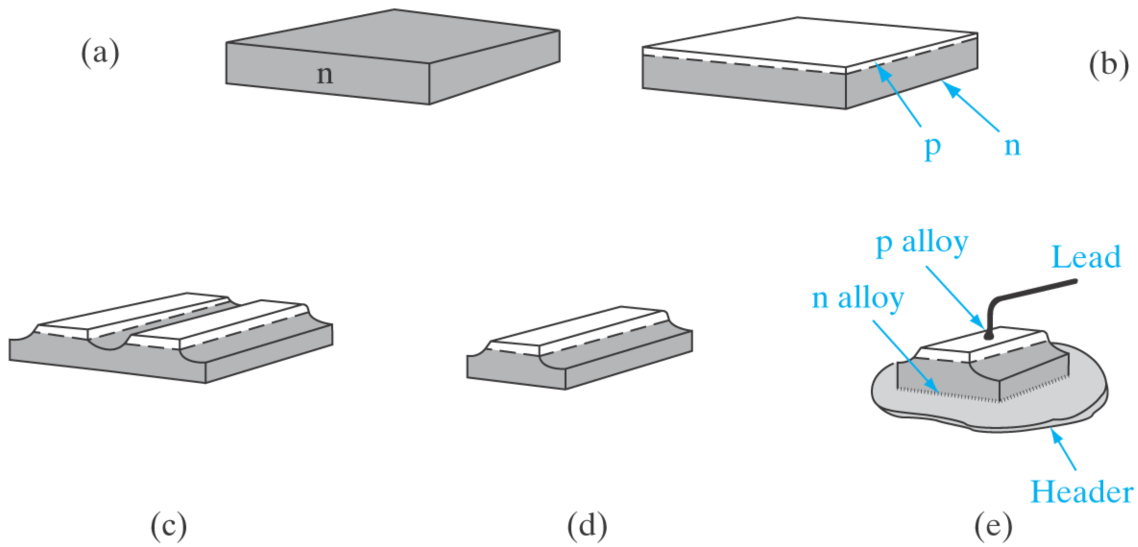


Figure 8.22

Fabrication of a simple junction laser: (a) degenerate n-type sample; (b) diffused p layer; (c) isolation of junctions by cutting or etching; (d) individual junction to be cut or cleaved into devices; (e) mounted laser structure.

Heterojunction Lasers

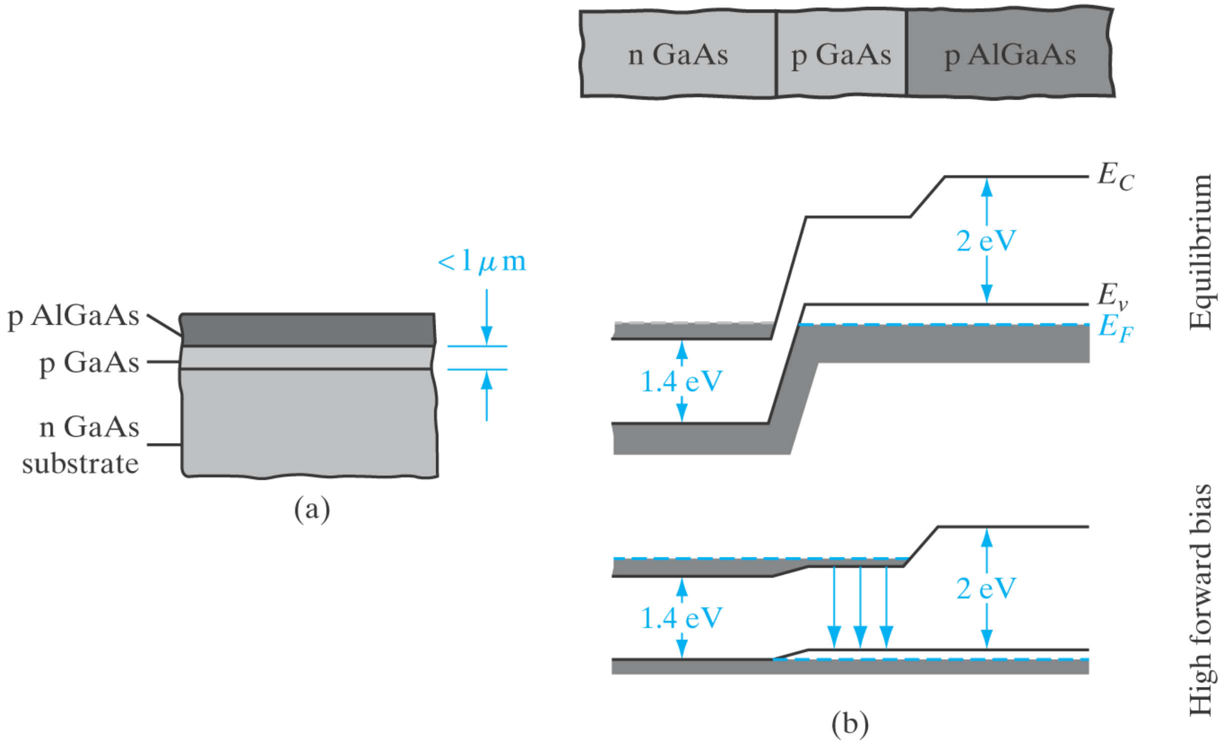


Figure 8.23

Use of a single heterojunction for carrier confinement in laser diodes: (a) AlGaAs heterojunction grown on the thin p-type GaAs layer; (b) band diagrams for the structure of (a), showing the confinement of electrons to the thin p region under bias.

Double Heterojunction Laser

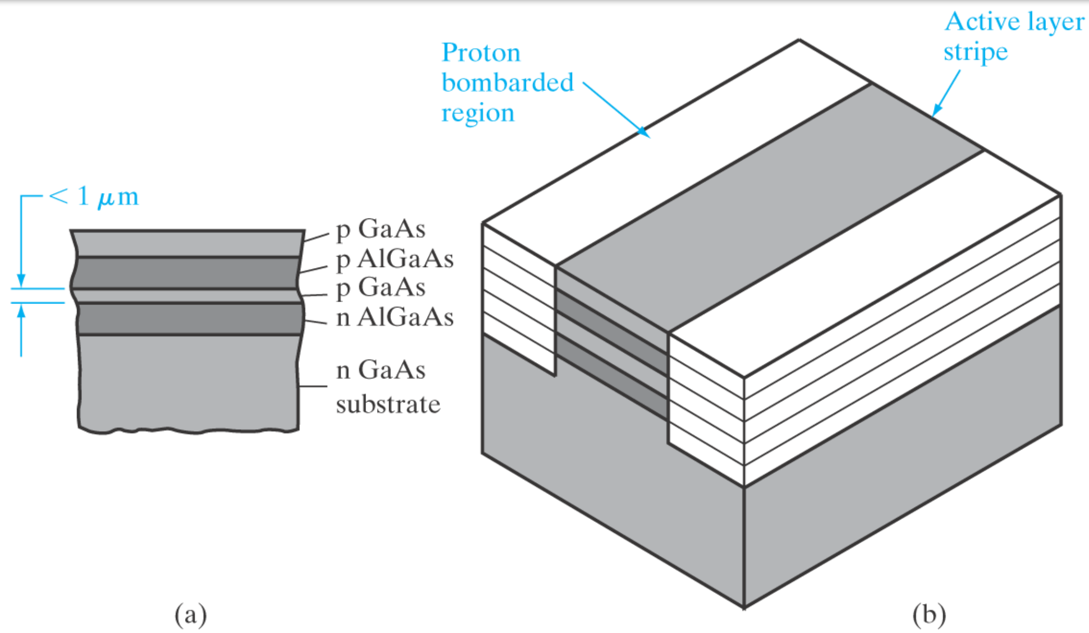


Figure 8.24

A double-heterojunction laser structure: (a) multiple layers used to confine injected carriers and provide waveguiding for the light; (b) a stripe geometry designed to restrict the current injection to a narrow stripe along the lasing direction. One of many methods for obtaining the stripe geometry, this example is obtained by proton bombardment of the shaded regions in (b), which converts the GaAs and AlGaAs to a semi-insulating form.

Separate Confinement Heterostructure

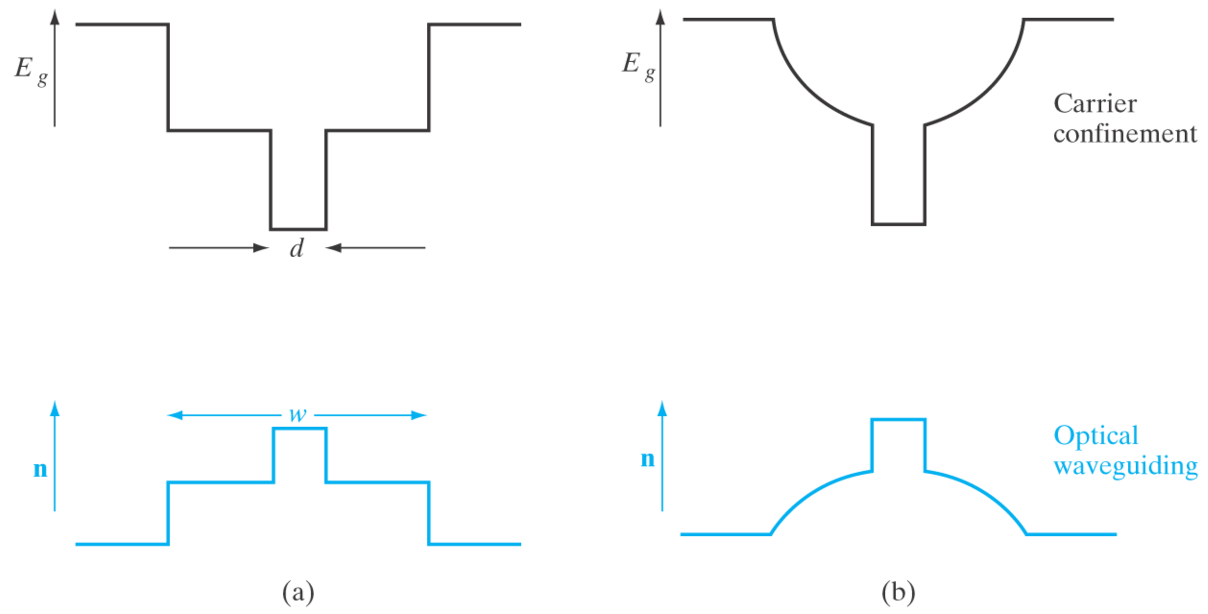


Figure 8.25

Separate confinement of carriers and waveguiding: (a) use of separate changes in AlGaAs alloy composition to confine carriers in the region (d) of the smallest band gap and to obtain waveguiding (*w*) at the larger step in the refractive index; (b) grading the alloy composition, and therefore the refractive index, for better waveguiding and carrier confinement.

Vertical Cavity Surface Emitting Laser

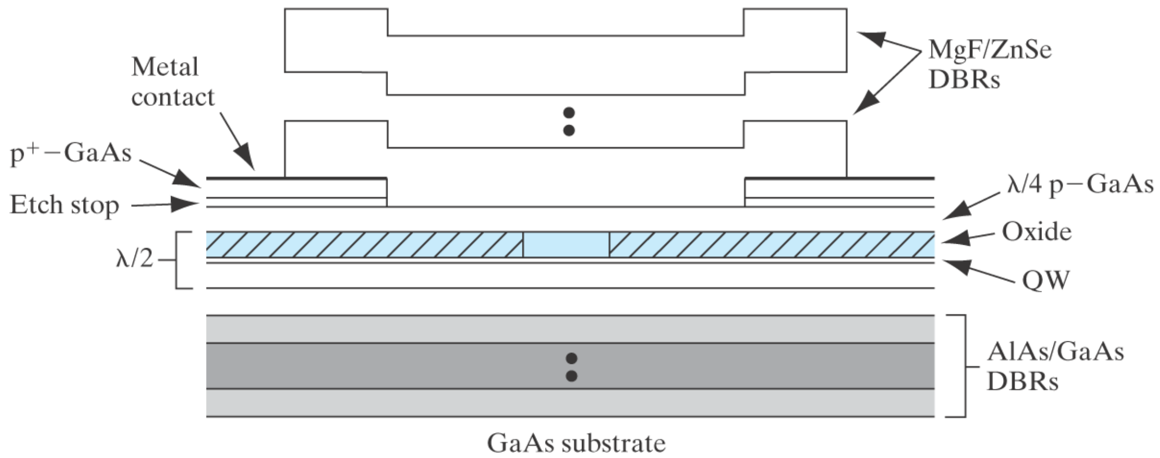
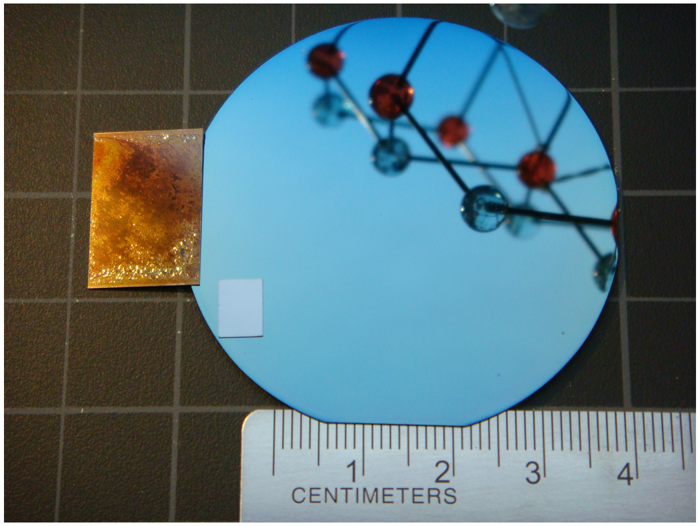
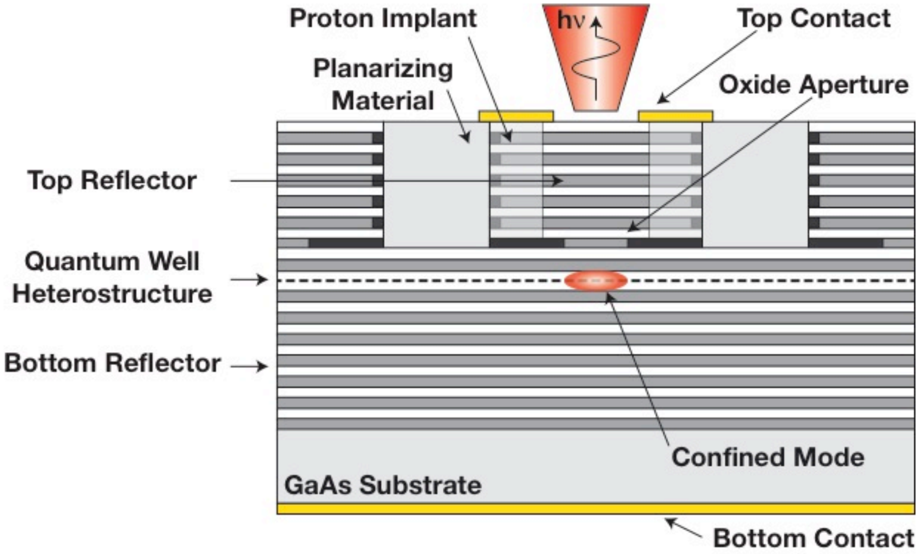


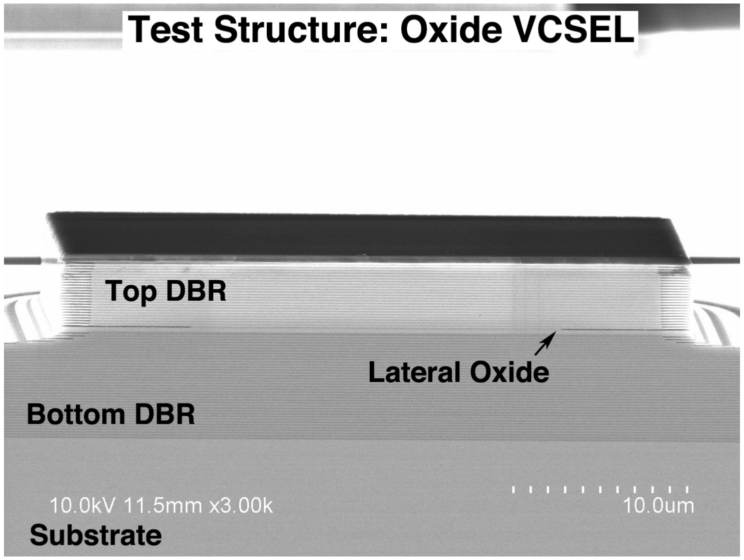
Figure 8.26

Schematic cross section of oxide-confined vertical cavity surface-emitting laser diode. [D. G. Deppe etal., *IEEE J. Selected Topics in Quantum Elec*., 3(3) (June 1997): 893–904].

VCSELs


1
2
3
4
CENTIMETERS


Proton Implant
hν
Top Contact
Planarizing Material
Oxide Aperture
Top Reflector
Quantum Well Heterostructure
Bottom Reflector
Confined Mode
GaAs Substrate
Bottom Contact


Test Structure: Oxide VCSEL
Top DBR
Lateral Oxide
Bottom DBR
10.0kV 11.5mm x3.00k
10.0um
Substrate

Assignments

Assignments

- Homework assigned every Friday, due following Friday
- Reading from Streetman's book:
  - Mon 3/26: §'s 5.4, 5.4.1, 5.4.2
  - Wed 3/28: § 5.5.4
  - Fri 3/30: §'s 8.1.1, 8.1.2, 8.1.3
  - Mon 4/2: §'s 8.2.1, 8.2.2, 8.3, 8.4.1, 8.4.2, 8.4.3, 8.4.4, 8.4.5
  - Wed 4/4: §'s 5.7.1, 5.7.2, 5.7.3
  - Fri 4/6: §'s 6.4.1, 6.4.2
- Chapters 5, 6, 7, 8, and 9 in Pierret cover similar material

Topics for Next Lecture

Outline, 4/4/18

- Finish Lasers and LEDs
- Metal-Semiconductor 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.

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

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)

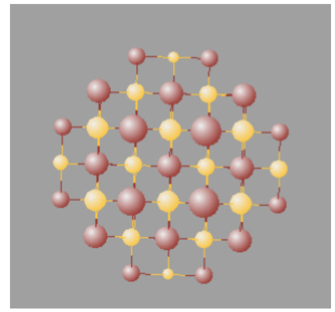
By the time of the Final Exam, after 44 class periods, the students should be able to do all of the items listed under A and B, plus the following:

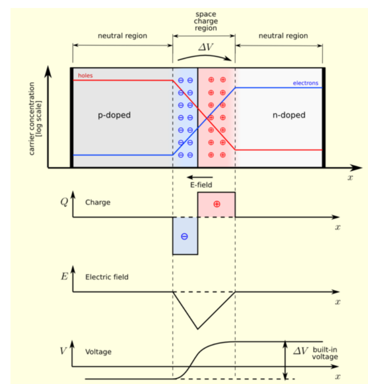
26. Calculate the terminal parameters of a BJT in terms of the material properties and device structure.
27. Estimate the base transport factor “B” of a BJT and rank-order the internal currents which limit the gain of the transistor.
28. Determine the rank order of the electrical fields in the different 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.

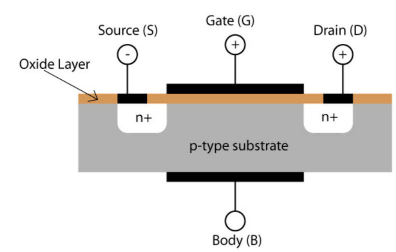
https://my.ece.illinois.edu/courses/description.asp?ECE340

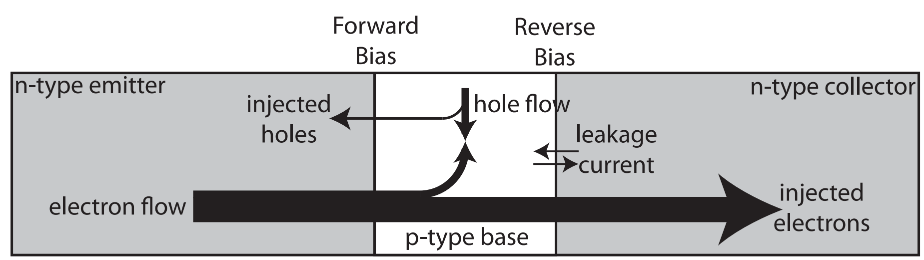
Course Purpose & Objectives

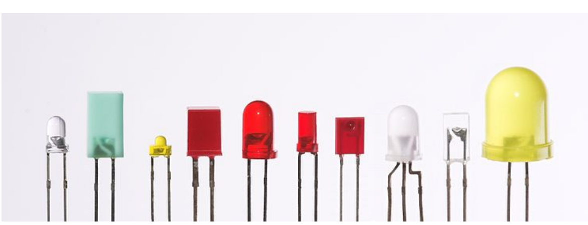
- Introduce key concepts in semiconductor materials
- Provide a basic understanding of p-n junctions
- Provide a basic understanding of light-emitting diodes and photodetectors
- Provide a basic understanding of field effect transistors
- Provide a basic understanding of bipolar junction transistors











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 [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

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, 7^{th} 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