Xi'an Jiaotong-Liverpool University
西交利物浦大學

EEE109: Electronic Circuits

Organizational Information & Chapter 1

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TIME TABLE FOR EEE109 CAN BE FOUND ON ICE PAGE, AND IT CHANGES EVERY YEAR

MODULE HANDBOOK IS ALSO UPLOADED ON ICE, WHICH PROVIDES YOU THE ESSENTIAL INFORMATION ABOUT THIS MODULE, SUCH AS MODULE STRUCTURE, ASSESSMENT METHODS, TEACHING PLAN, AND ETC.

VIDEOS ON MICROELECTRONICS CAN ALSO BE FOUND ON THE TOP OF ICE PAGE, WHICH COULD HELP YOU UNDERSTAND.

Class Rules

- Attendance of the classes is IMPORTANT.

Reason 1: If you miss the class once for a good reason, your chance to miss more classes increases “exponentially”

Reason 2: Important announcements are usually given in the beginning and the end of the class.

Reason 3: There will be random class tests/assignments during the semester.

Reason 4: Enjoy the company of your friends in the battle field of classroom fighting for knowledge that will enrich your life.

Mandatory Textbook

- Mandatory Book:

  Microelectronic Circuit Analysis and Design, *4rd Ed*, *McGraw Hill*, by Donald Neaman

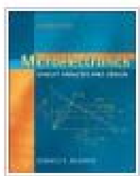
- Additional References Books:

1. A. S. Sedra and K. C. Smith, Microelectronic Circuits, 5th Ed, Oxford University Press, 2004.
2. David Comer and Donald Comer, Fundermentals of Electronic Circuit, John Wiley
3. A. R. Hambley, Electrical Engineering Principles and Applications, McGraw-Hill

Mandatory Book:

Microelectronic Circuit Analysis and Design, *4rd Ed, McGraw Hill*, by Donald Neaman

3. Microelectronics : circuit analysis and design / Donald A. Neamen.



Book

By: Neamen, Donald A.. New York : McGraw-Hill, c2010. online resource. Language: English, Database: XJTLU LIBRARY'S OPAC

Subjects: Electronic circuit design; Semiconductors -- Design and construction

Retrieve Catalogue Item

OUR LIB HAS THE E-VERSION OF THIS BOOK, WHICH MEAN S YOU COULD HAVE ACCESS TO THIS BOOK IN UNIVERSITY DOMAIN.

Learning Outcomes

On successful completion of this module the student should:

- understand the behaviour, important properties, equivalent circuit representations and applications of diodes and transistors;
- understand circuit biasing, the role of decoupling capacitors and the performance of some commonly used circuit configurations and their practical significance;
- understand amplifier circuit design and circuit analysis;
- understand frequency response of amplifiers via simulation.
- Understand output stage and power amplifier.

Intellectual Abilities

On successful completion of this module the student should be able to

- analyse simple transistor circuits;
- determine components to meet a specification;
- design various types of amplifiers.

Practical Skills

On successful completion of this module the student should be able to:

- determine device properties from characteristics;
- calculate the output voltage and regulation of simple rectifier and stabilizer circuits;
- perform simple analysis of circuits containing bipolar and MOS transistors;
- construct and test simple transistor circuits and amplifiers;
- simulate frequency response of amplifiers using PSpice.

Module Assessment

Assessment Components:

1. Final Exam, 60 %
2. Midterm Exam, 15%
3. Assignments/HWs, 10 %
4. Lab/Lab reports 15%

Note:

a) You will not pass if you don't take the Midterm/HW/Lab seriously

b) Resit is in August 2016 and applies students who fail the class.

Module Assessment

Homework and Report Submission Requirements:

- Do not be late; No late HW will be accepted
- Do not do them in the class, *turn in your work electronically only (no hardcopy submissions)*
- Submit electronic copy in PDF format **only**
- Due in preannounced time and date via ICE

Syllabus

Course Content by Week:

Week 1: Chapter 1 Semiconductor Materials and Diodes
Week 2, 3: Chapter 2 Diode Circuits
Week 3, 4: Chapter 3 The Bipolar Junction Transistor
Week 5: Chapter 4 Basic Bipoler Amplifier
Week 6: Midterm Review.

Week 7: Midterm Exam

Week 8: Chapter 5&6 Frequency Response
Week 9, 10: Chapter 7 Output Stages and Power Amplifiers
Week 10, 11: Chapter 8 The Field-Effect Transistor
Week 12: Chapter 9 Basic FET Amplifier
Week 13, 14: Final Review

Lab Arrangement

Lab Schedule:

Week 8: Lab 1 (class 1) - Diodes Characteristics and Their Applications

Week 9: Lab 1 (class 2) - Diodes Characteristics and Their Applications

Week 10: Lab 2 (class 1) - Transistors and Their Applications

Week 11: Lab 2 (class 2) - Transistors and Their Applications

Week 12: Lab 3 PSpice lab (Class 1&2) – Frequency Response of BJT Amplifiers

Lab Reports:

3 Lab reports (15 % of module credit)

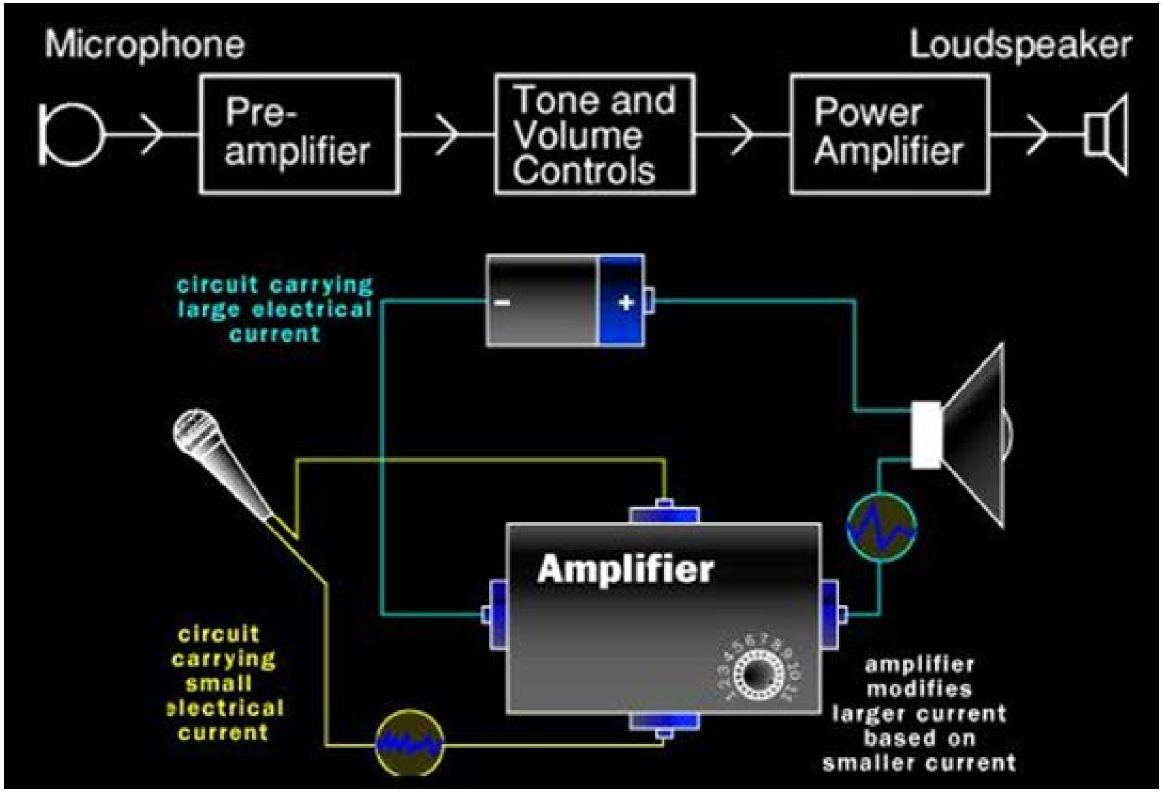
TAs:

5 TAs available

WHY I NEED TO LEARN THIS MODULE?

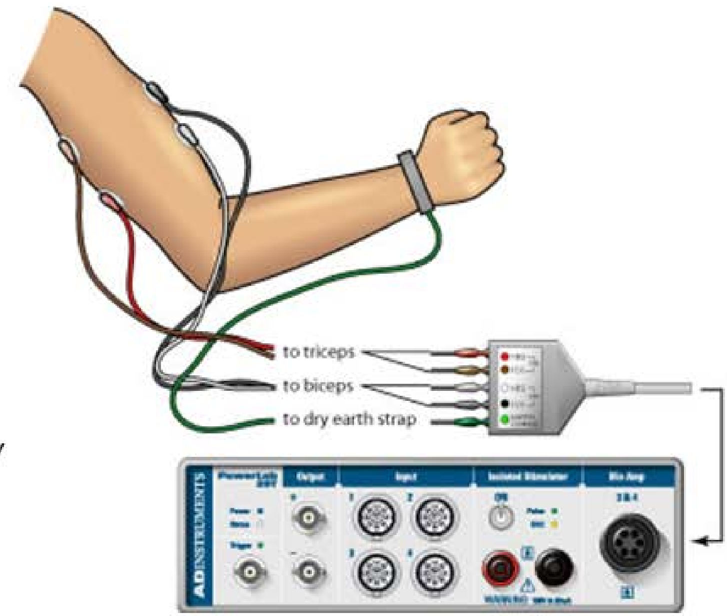
engineering-the-world-through-analog

Audio System

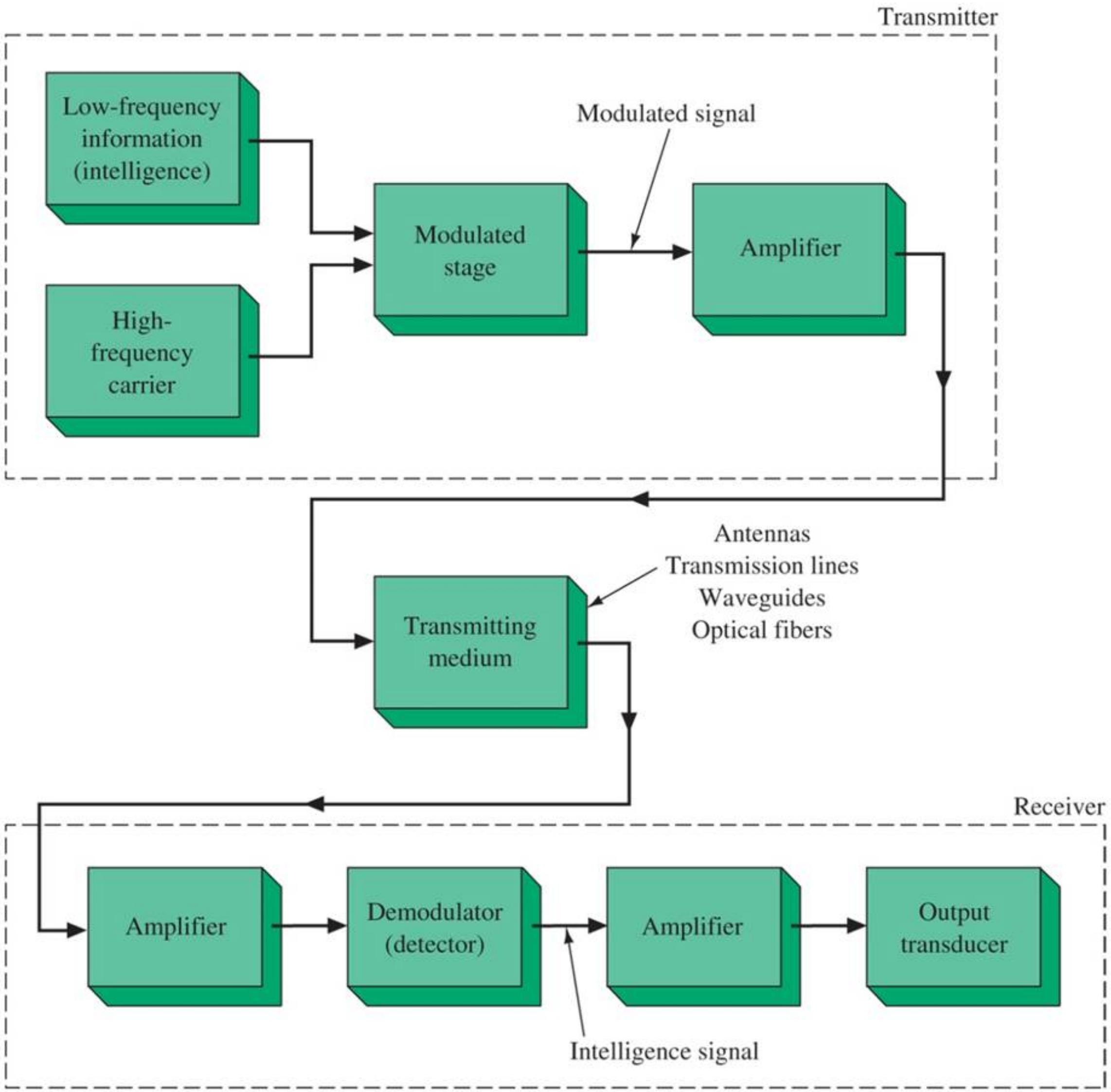


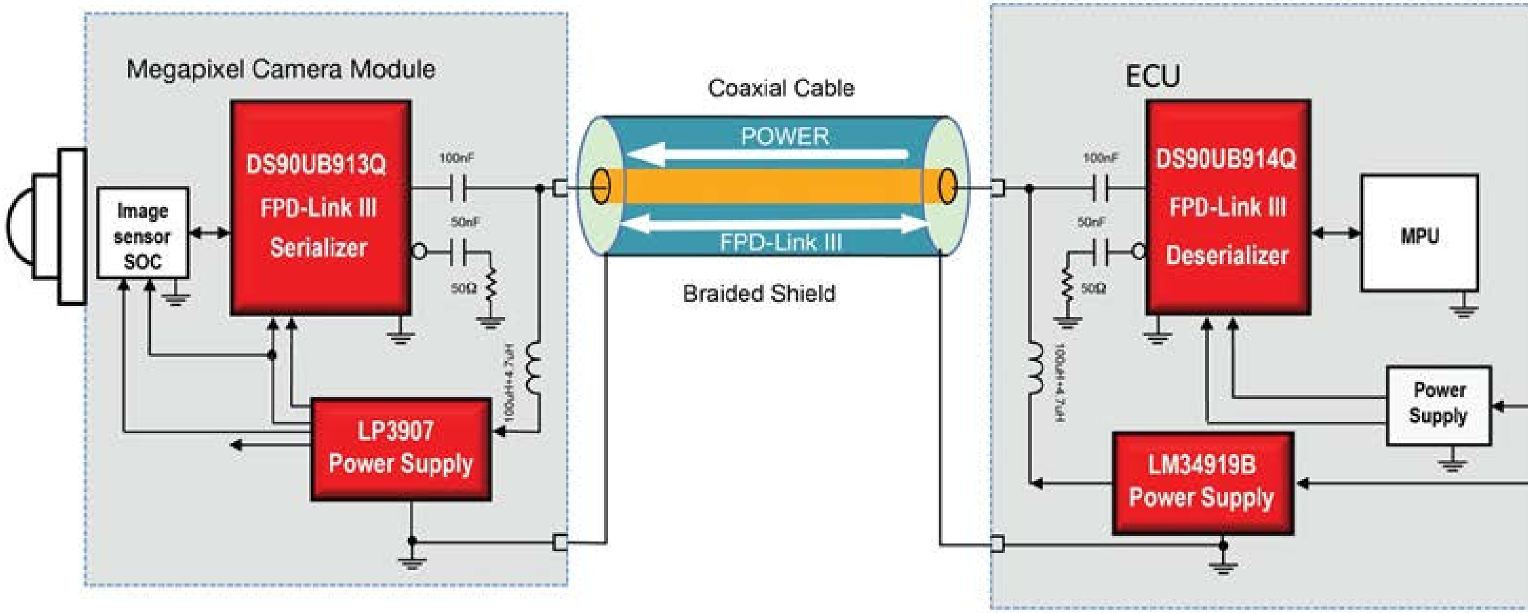
engineering-the-world-through-analog
Electromyogram Detection and Analysis

Muscles generate voltages around 100 mV when they contract. These voltages are greatly attenuated by internal tissue and the skin, and they are weak but measurable at the surface of the skin.



THE STRUCTURE OF MODERN COMMUNICATION SYSTEM



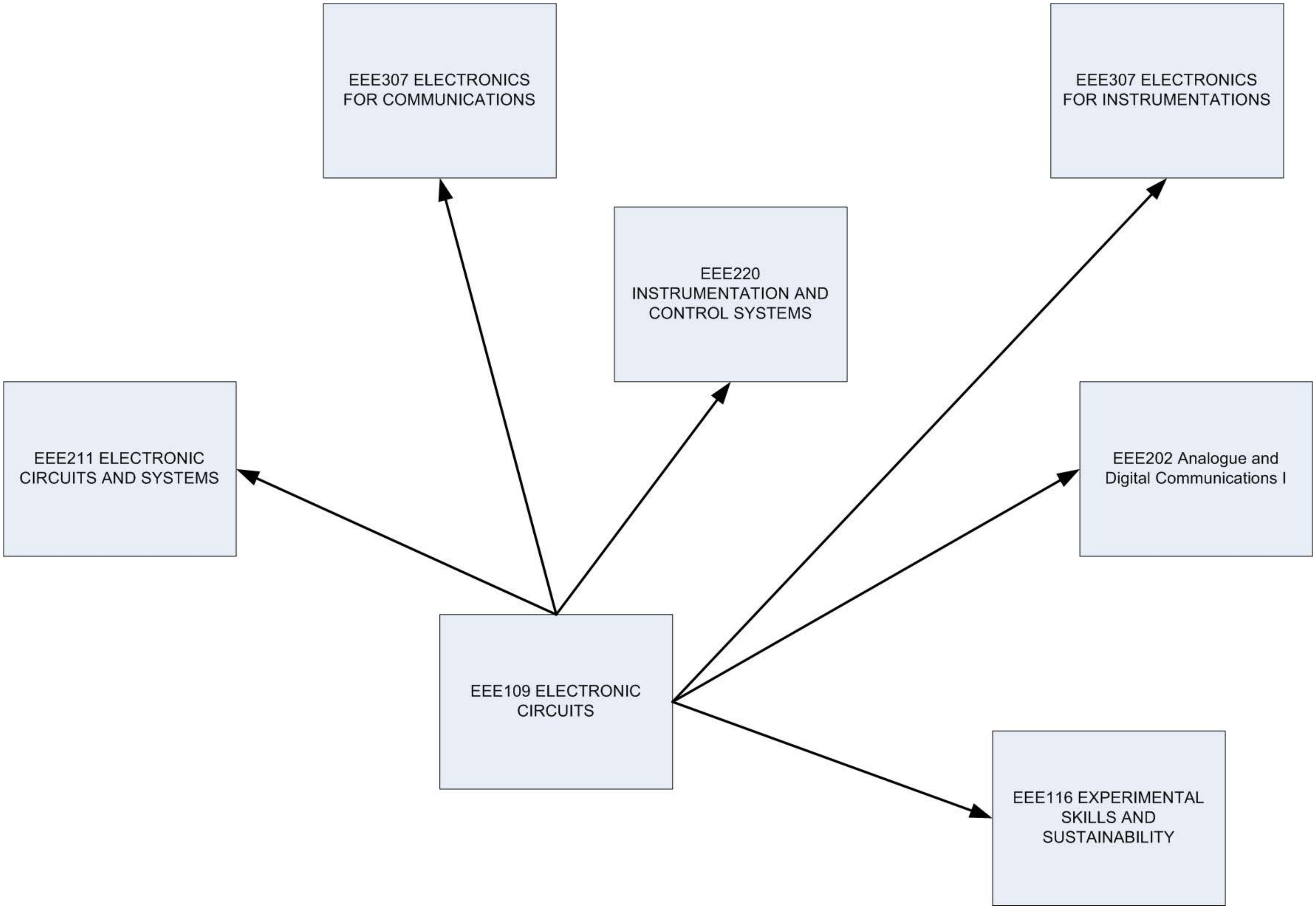


Common low impedance GND for all components (no GND shifts)

Our lives are surrounded by ANALOG everywhere we go. That's not news to the Analog Wire audience, but it may surprise some that in this age of digital electronics, analog technology is more pervasive and impactful than ever. In everything from **power tools** to a **runner's heart-rate monitor** to the **factory robot**, analog chips are managing batteries or power from the wall, converting and conditioning signals, and providing the system interface. Technology has made and will continue to make an impact on the way we live, learn, work and play.

-Hagop Kozanian @TI

http://e2e.ti.com/blogs_/b/analogwire/archive/2013/06/07/**engineering-the-world-through-analog**


EEE307 ELECTRONICS FOR COMMUNICATIONS
EEE307 ELECTRONICS FOR INSTRUMENTATIONS
EEE220 INSTRUMENTATION AND CONTROL SYSTEMS
EEE211 ELECTRONIC CIRCUITS AND SYSTEMS
EEE202 Analogue and Digital Communications I
EEE109 ELECTRONIC CIRCUITS
EEE116 EXPERIMENTAL SKILLS AND SUSTAINABILITY

Background Knowledge

What is Electronics Anyway?

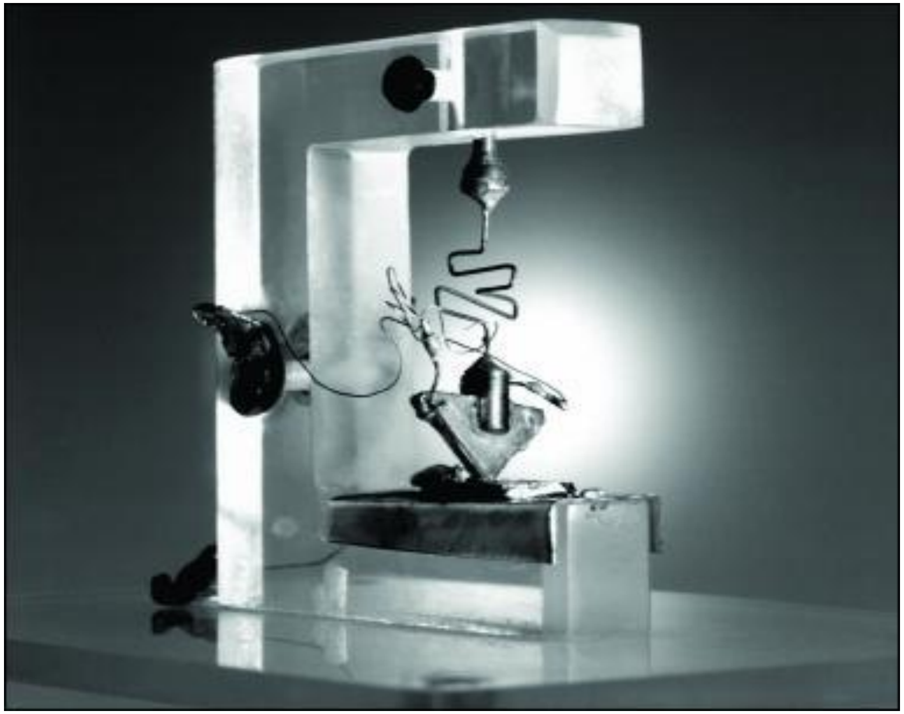
Microelectronics, Nanoelectronics, Optoelectronics, Terahertz Electronics, Power Electronics, Digital and Analog Electronics…

Def 1: **Electronics** is the branch of science that deals with the study of flow and control of electrons (electricity) and the study of their behavior and effects in vacuums, gases, and semiconductors, and with devices using such electrons. This control of electrons is accomplished by devices that resist, carry, select, steer, switch, store, manipulate, and exploit the electron.

Def 2: The institute of Radio Engineers has given a definition of electronics as "the field of science and engineering, which deals with electron devices and their utilization."

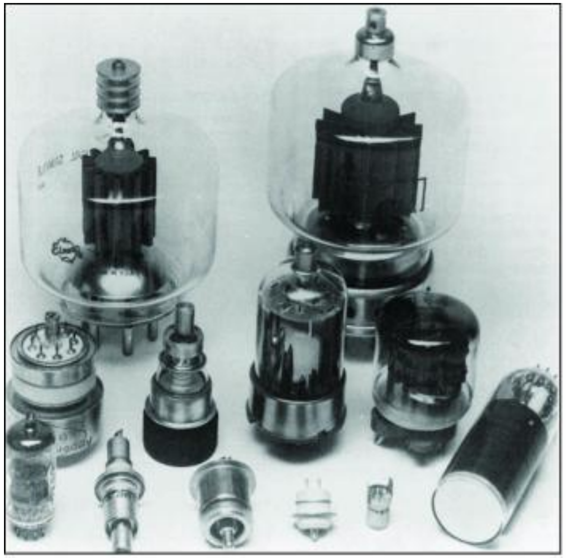
The Start of the Modern Electronics Era

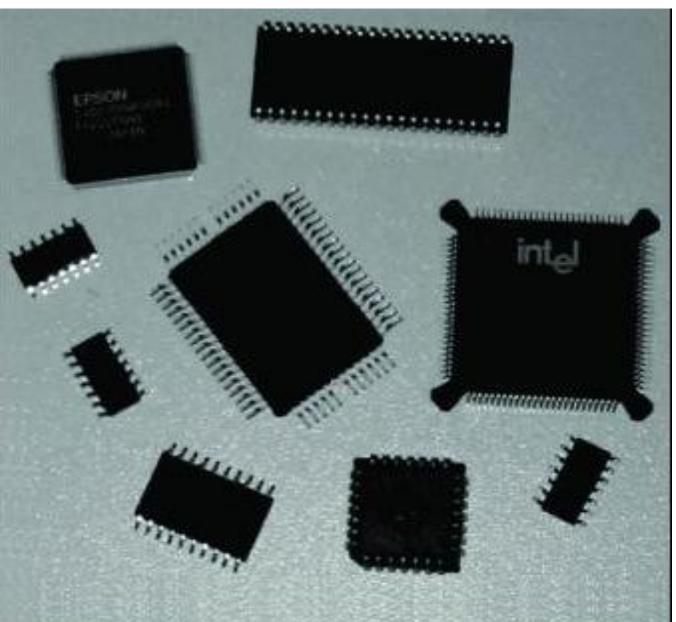
Bardeen, Shockley, and Brattain at Bell Labs - Brattain and Bardeen invented the bipolar transistor in 1947.



The first germanium bipolar transistor. Roughly 60 years later, electronics account for >10% (>8 trillion dollars) of the world GDP.
Note: World GDP ~78.9 Trillions in 2011

Evolution of Electronic Devices

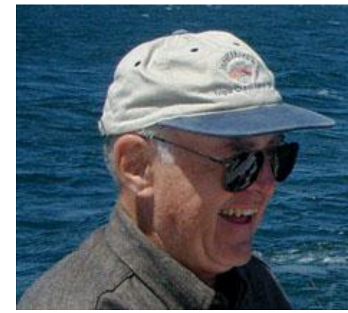




References by Jaeger/Blalock 7/1/03

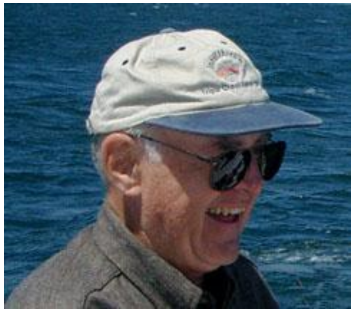
Microelectronics Proliferation

- The integrated circuit was invented in 1958.
- Moore’s Law (predicted in 1966).



- World transistor production has more than doubled every year for the past twenty years.
- Every year, more transistors are produced than in all previous years combined.
- Nanoelectronics is the new kid in the block!

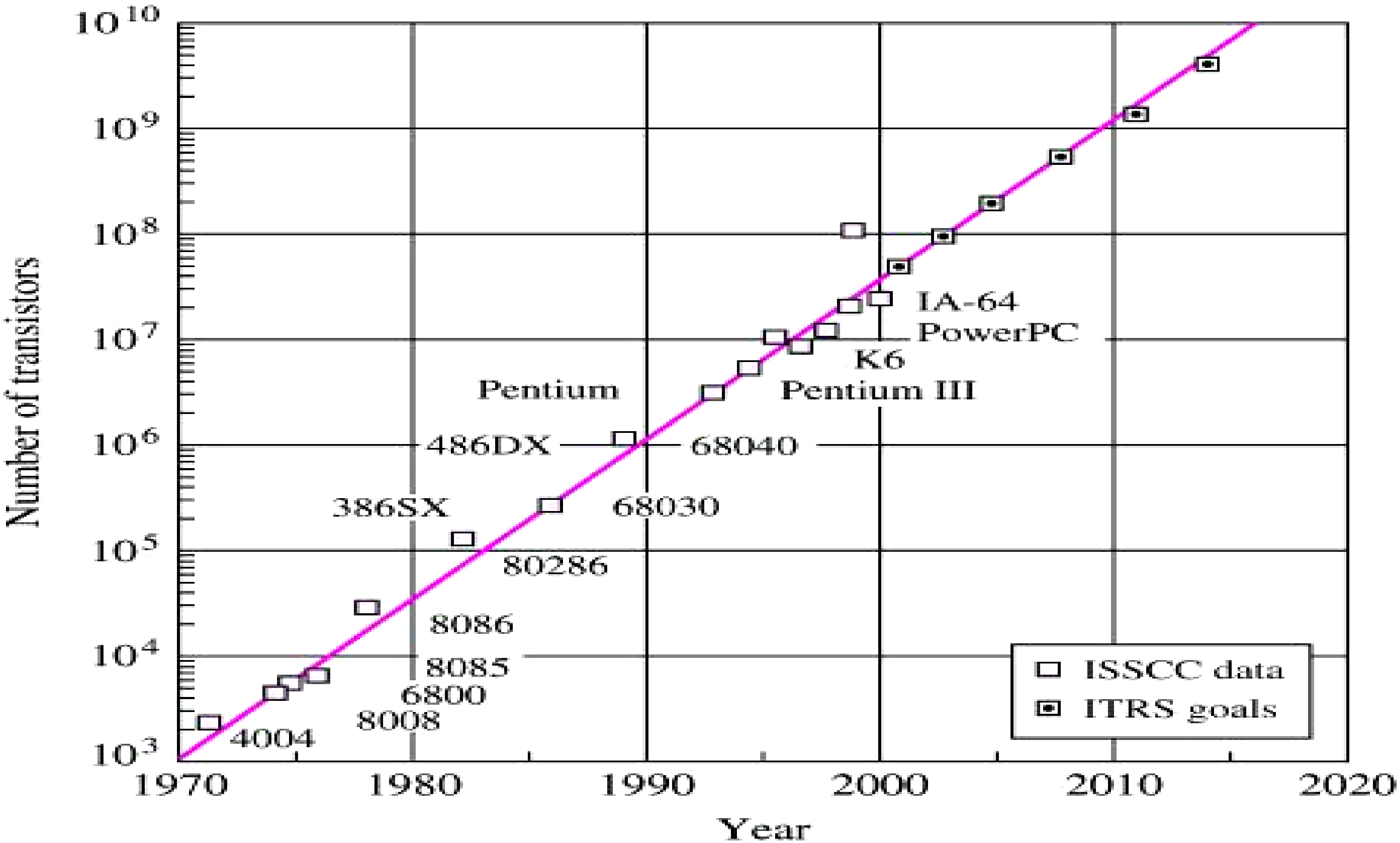
Microelectronics Proliferation



- On 13 April 2005, Gordon Moore stated in an interview that the law cannot be sustained indefinitely: "***It can't continue forever. The nature of exponentials is that you push them out and eventually disaster happens***". He also noted transistors would eventually reach the **limits of miniaturization** at **atomic** levels.

Microprocessor complexity versus time

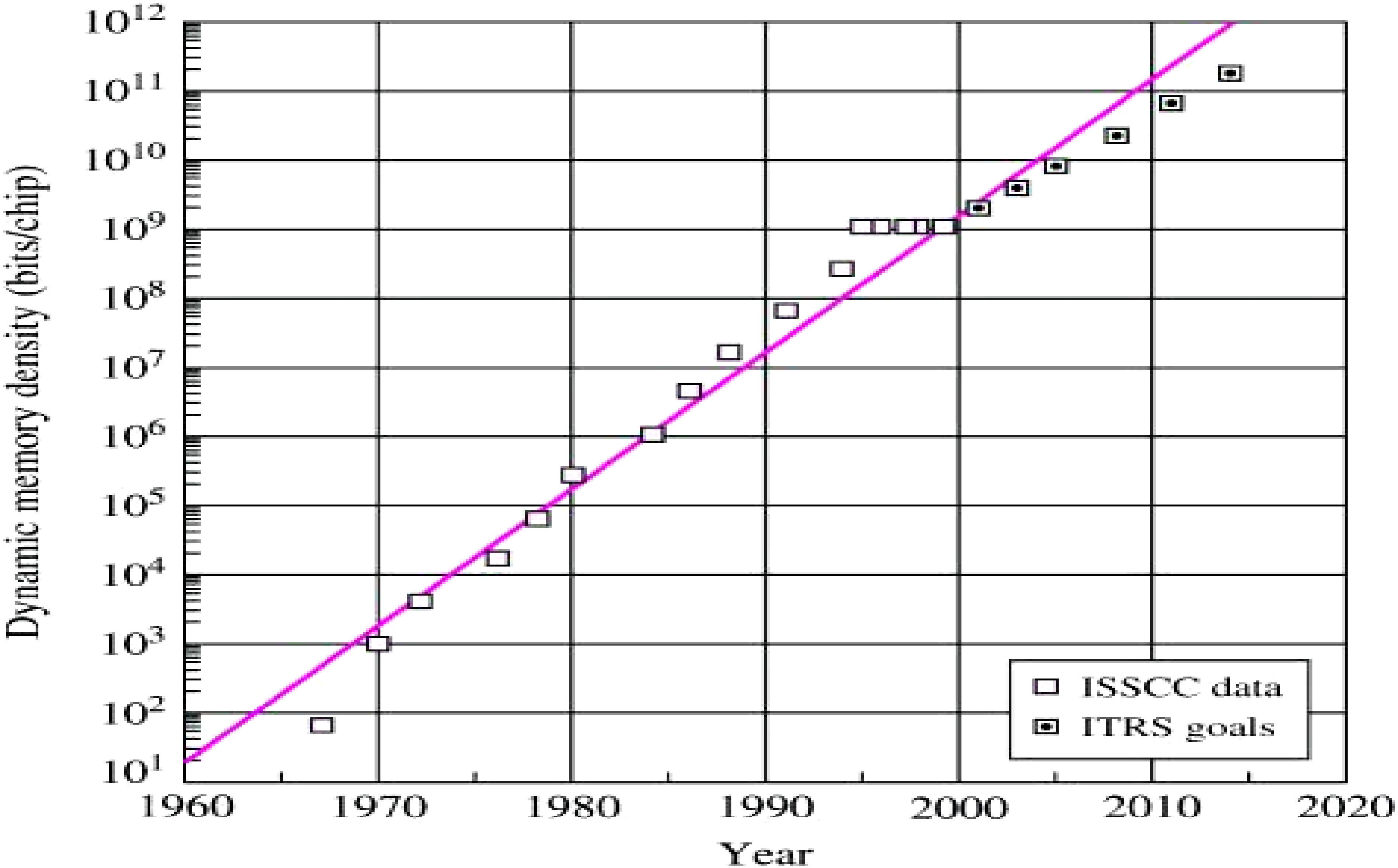
From Jaeger/Blalock 7/1/03



ISSCC: IEEE International Solid-State Circuits Conference

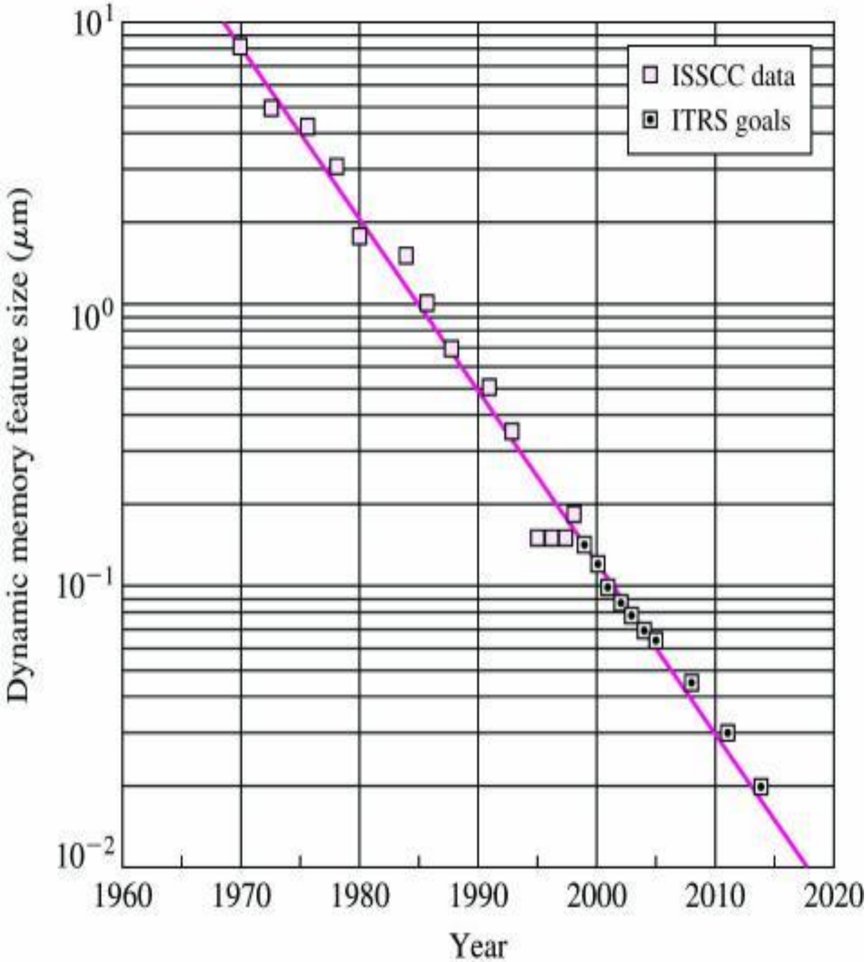
ITRS: International Technology Roadmap for Semiconductors

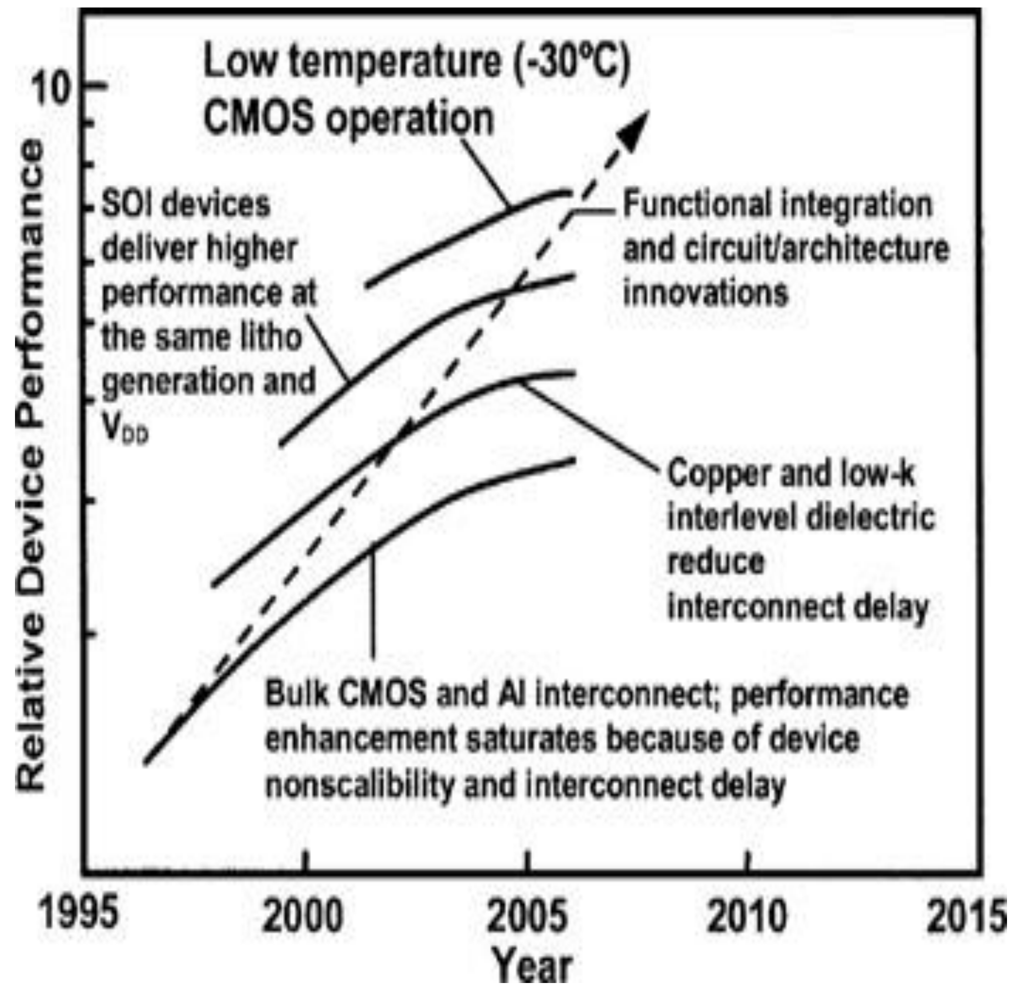
Memory chip density versus time



Taken from Jaeger/Blalock 7/1/03

Device Feature Size

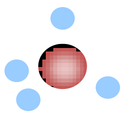




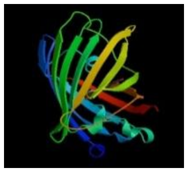
Take by Permission from Jaeger/Blalock 7/1/03

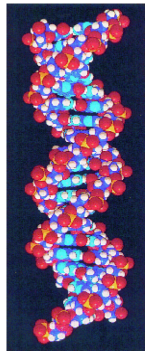
Length Scales

Simple molecules <1nm



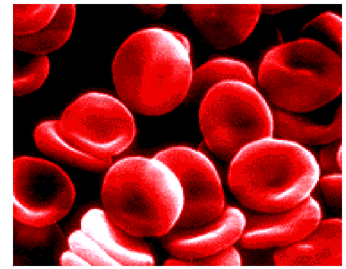
DNA proteins nm



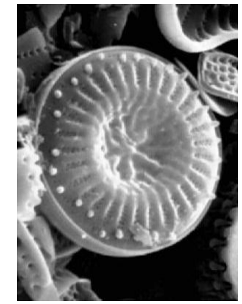


bacteria 1 μm

red blood cell ~5 μm (SEM)

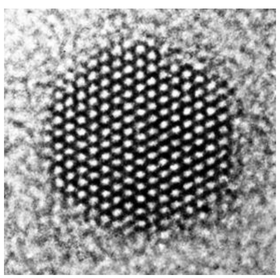


Diatom 30 μm

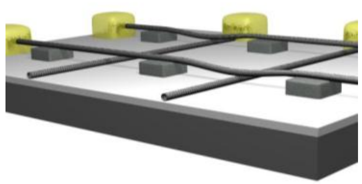


nm μm m

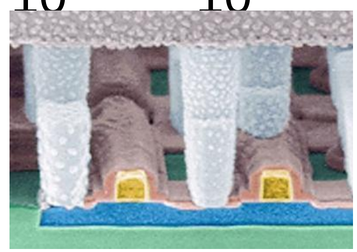
10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2}



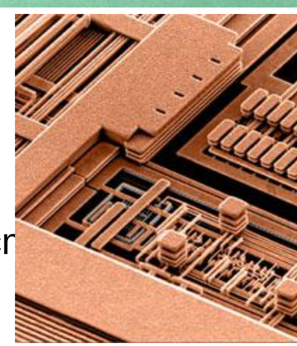
semiconductor nanocrystal (CdSe) 5nm



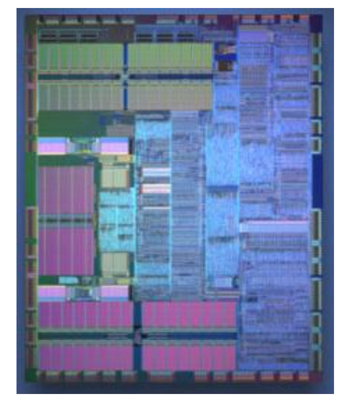
Nanometer memory element (Lieber) 10^{12} bits/cm^2 (1Tbit/cr



SOI transistor width 0.12μm



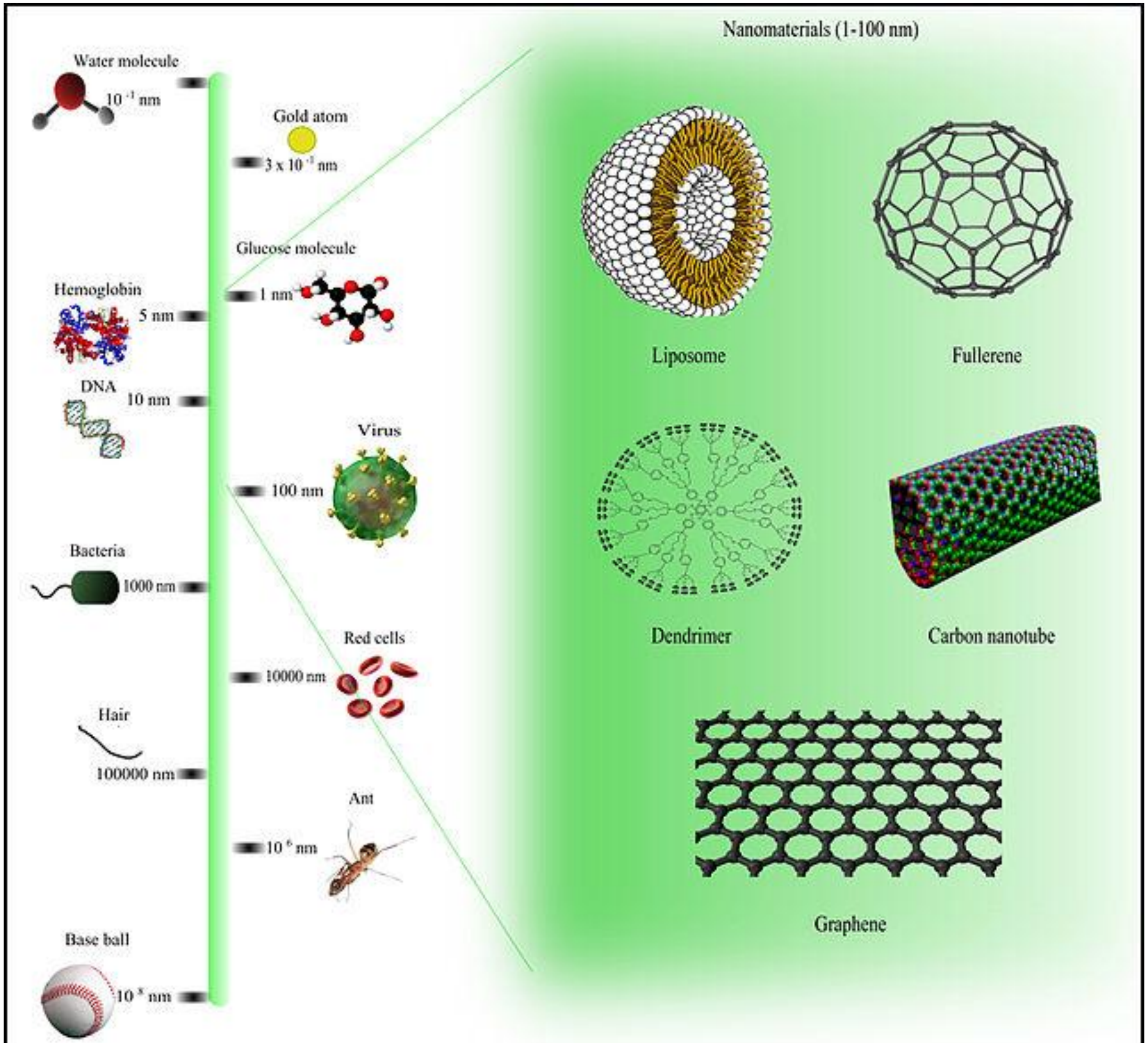
Circuit design Copper wiring width 0.2μm



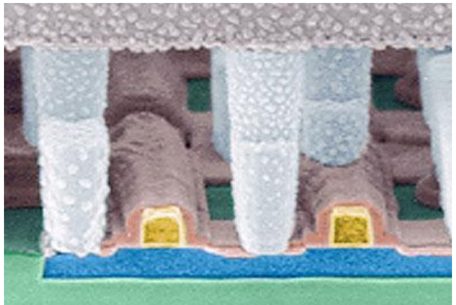
IBMPowerPC750™ Microprocessor7.56 mm × 8.799mm 6.35×10^6 transistors

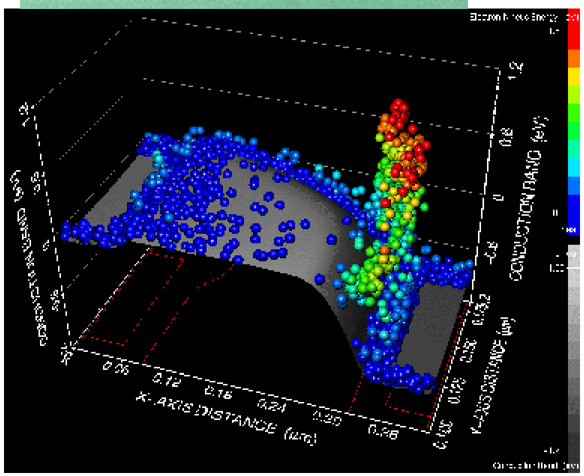
Photo credits, bio, L-R GFP: RCSB Protein Data Bank http://www.rcsb.org/pdb/ E.Coli: Dennis Kunkel http://www.pbrc.hawaii.edu/kunkel/catalog/by_category/ Red Blood Cells: James A. Sullivan, www.cellsalive.com Diatom: Dept of Biology, Indiana University Silicon, L-R CdSe nanocrystal: Andreas Kadavanich, Alivisatos Group, Dept of Chemistry, UC Berkeley Nanotube memory device: Lieber Group, Dept of Chemistry, Harvard University SOI transistor/Cu wiring/PowerPC Microprocessor chip: IBM

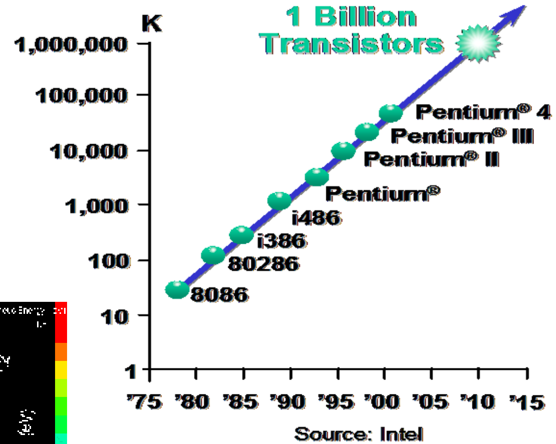
Comparison of Nanomaterial Sizes

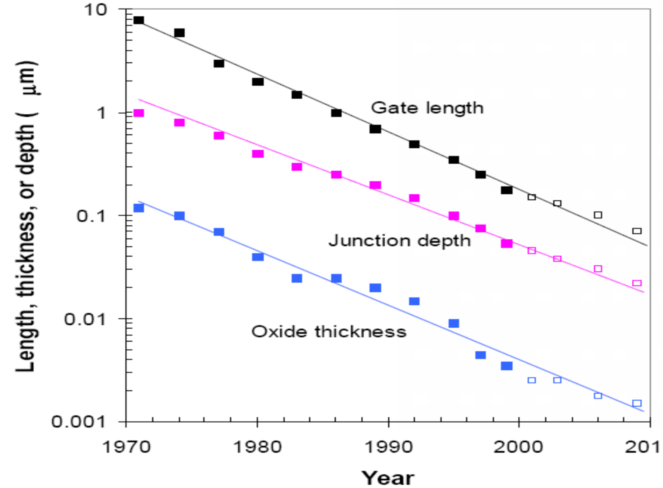


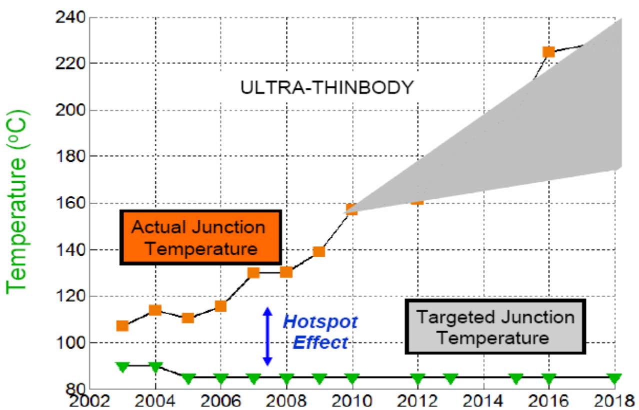
Revolution and Evolution in Electronics











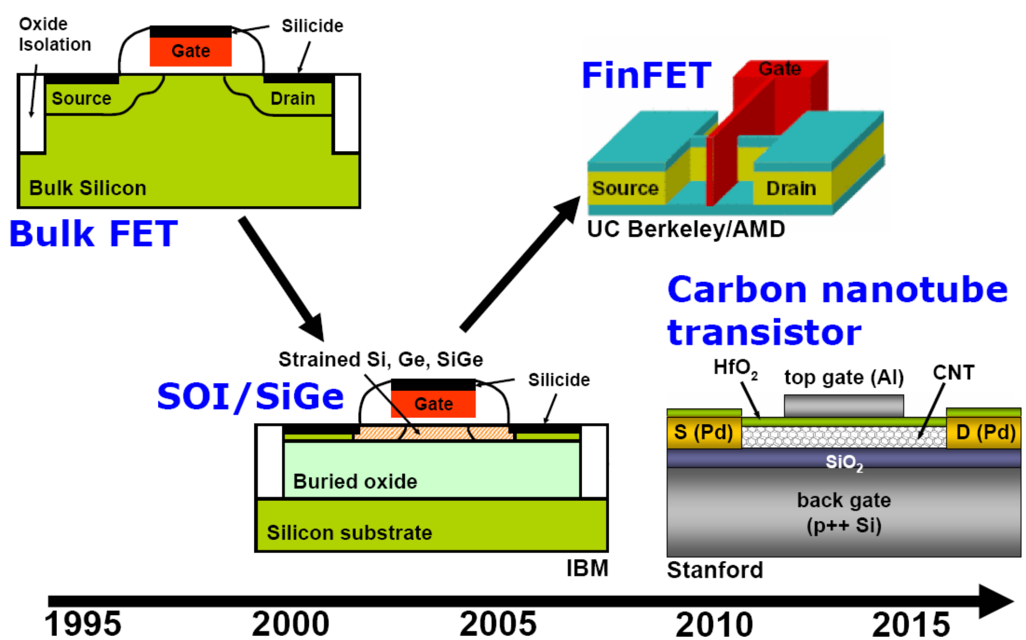
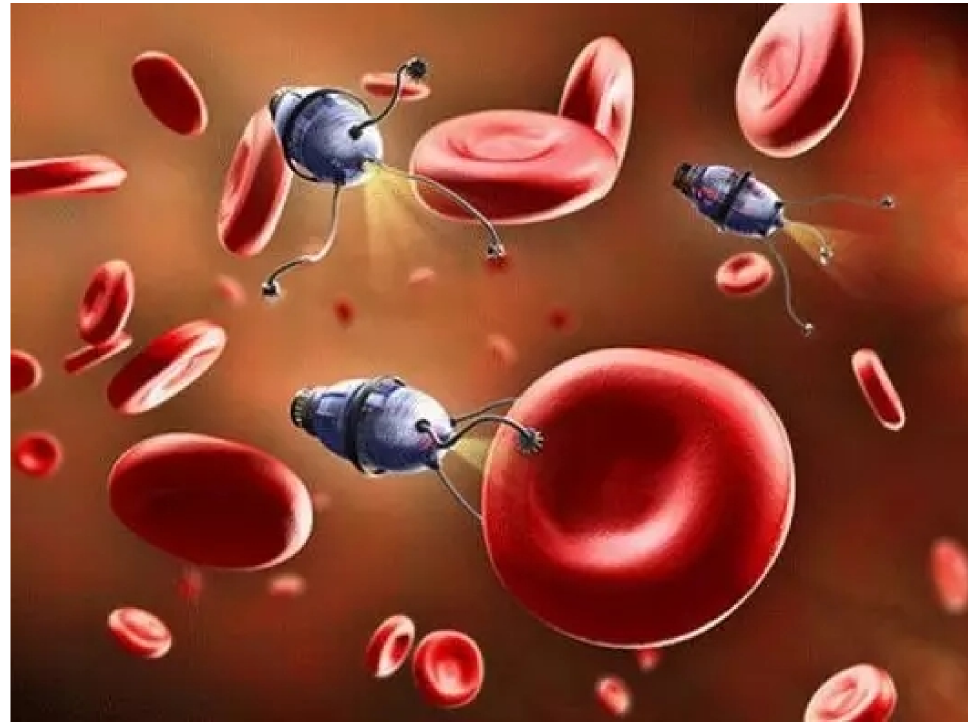


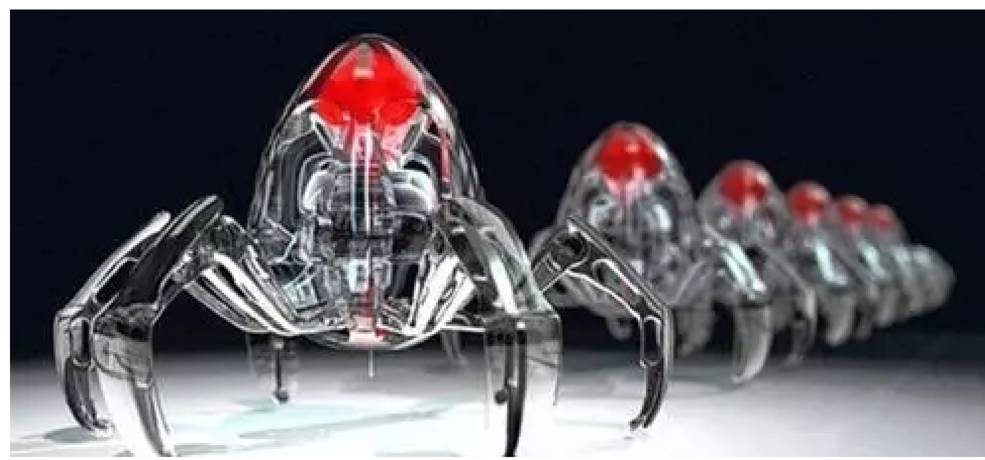
Photo credits, bio, L-R GFP: RCSB Protein Data Bank http://www.rcsb.org/pdb/ E.Coli: Dennis Kunkel http://www.pbrc.hawaii.edu/kunkel/catalog/by_category/ Red Blood Cells: James A. Sullivan, www.cellsalive.com Diatom: Dept of Biology, Indiana University Silicon, L-R CdSe nanocrystal: Andreas Kadavanich, Alivisatos Group, Dept of Chemistry, UC Berkeley Nanotube memory device: Lieber Group, Dept of Chemistry, Harvard University SOI transistor/Cu wiring/PowerPC Microprocessor chip: IBM

RAY KURZWEIL:

Human species, along with the computational technology it created, will be able to solve age-old problems…and will be in a position to change the nature of mortality.

https://www.ft.com/content/7a89c998-828d-11e7-94e2-c5b903247afd





Goals for Chapter 1

- Gain a basic understanding of semiconductor material properties
  - Two types of charged carriers that exist in a semiconductor
  - Two mechanisms that generate currents in a semiconductor

- Determine the properties of a pn junction
  - Ideal current–voltage characteristics of a pn junction diode

- Examine dc analysis techniques for diode circuits using various models to describe the nonlinear diode characteristics

- Develop an equivalent circuit for a diode that is used when a small, time-varying signal is applied to a diode circuit

- Gain an understanding of the properties and characteristics of a few specialized diodes

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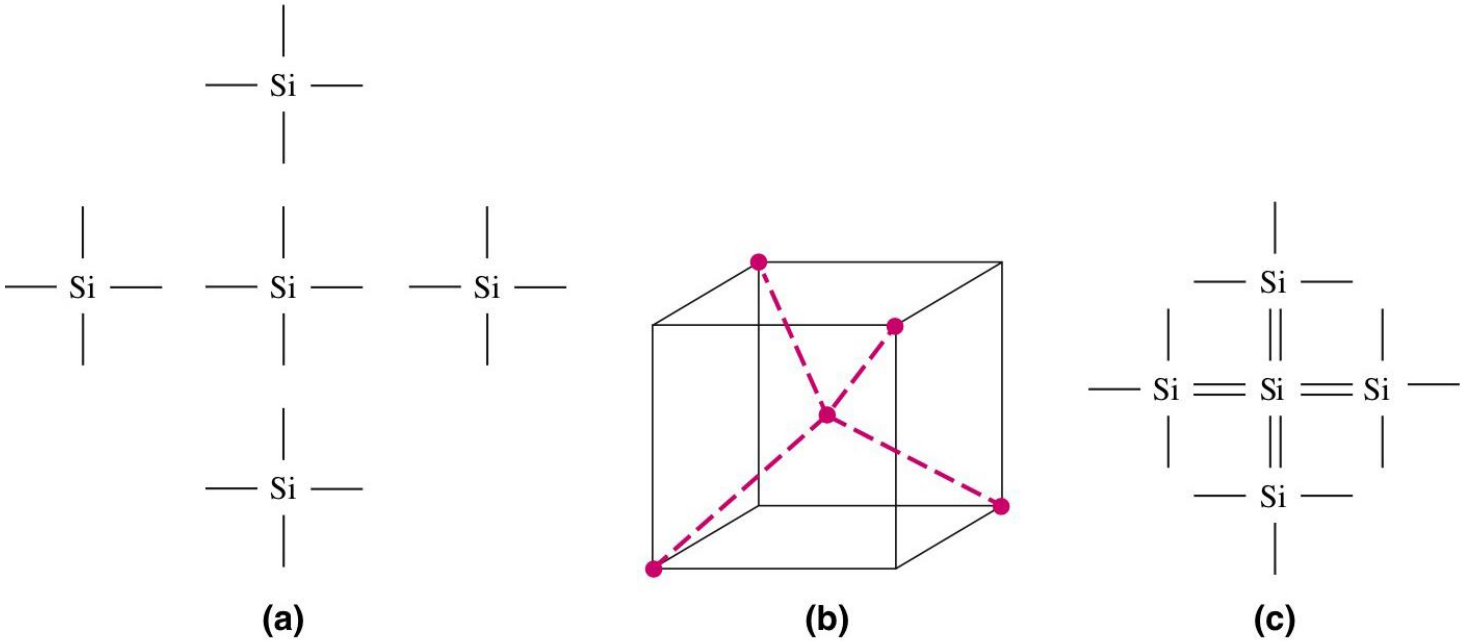
Semiconductor Material Properties

- Two types of charged carriers that exist in a semiconductor
- Two mechanisms that generate currents in a semiconductor

Intrinsic Semiconductors

- Ideally 100% pure material
  - Elemental semiconductors
    - Silicon (Si)
      - Most common semiconductor used today
    - Germanium (Ge)
      - First semiconductor used in p-n diodes
  - Compound semiconductors
    - Gallium Arsenide (GaAs)

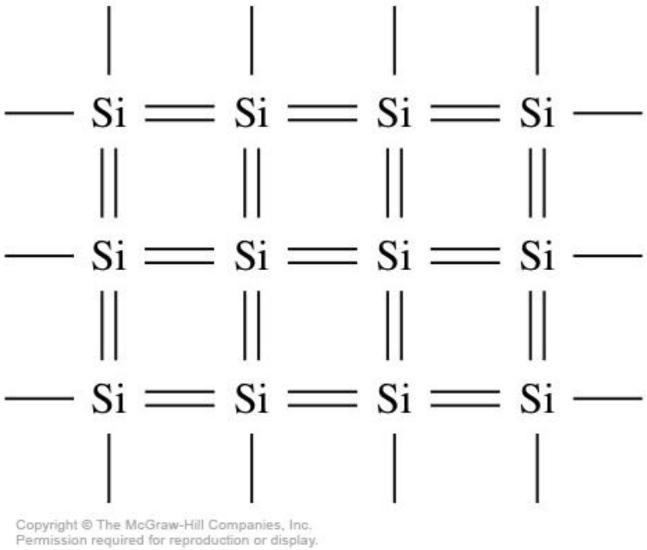
Silicon (Si)

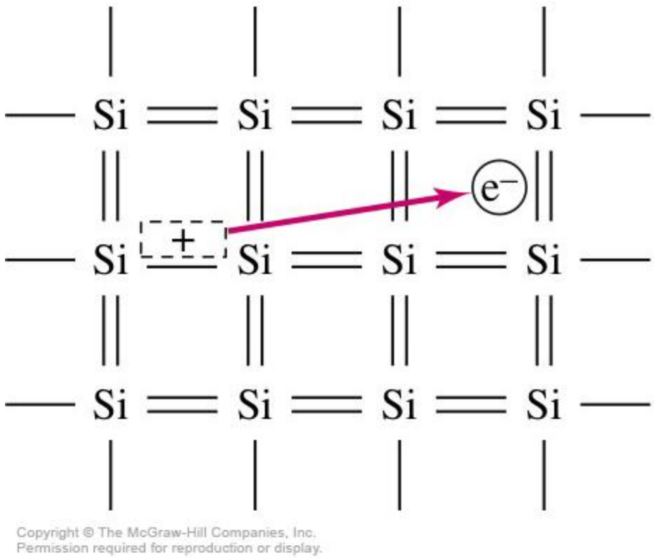


Covalent bonding of one Si atom with four other Si atoms to form tetrahedral unit cell.

Valence electrons available at edge of crystal to bond to additional Si atoms.

Effect of Temperature





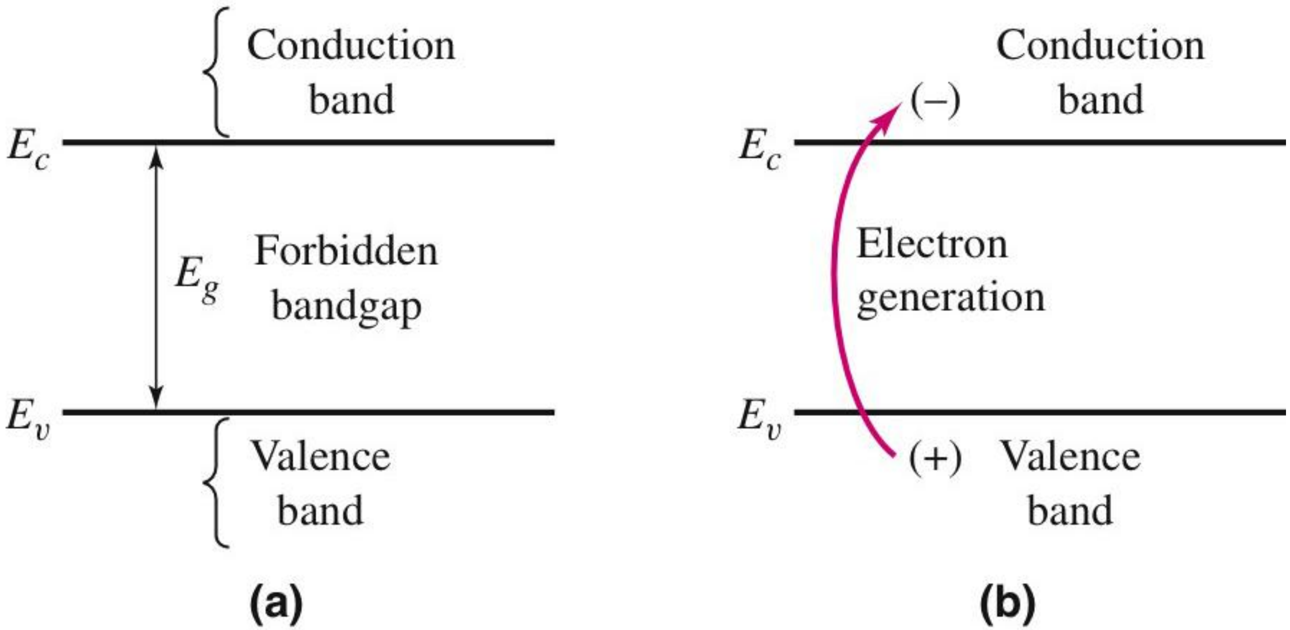
At 0K, no bonds are broken.

Si is an insulator.

As temperature increases, a bond can break, releasing a valence electron and leaving a broken bond (hole).

Current can flow.

Energy Band Diagram

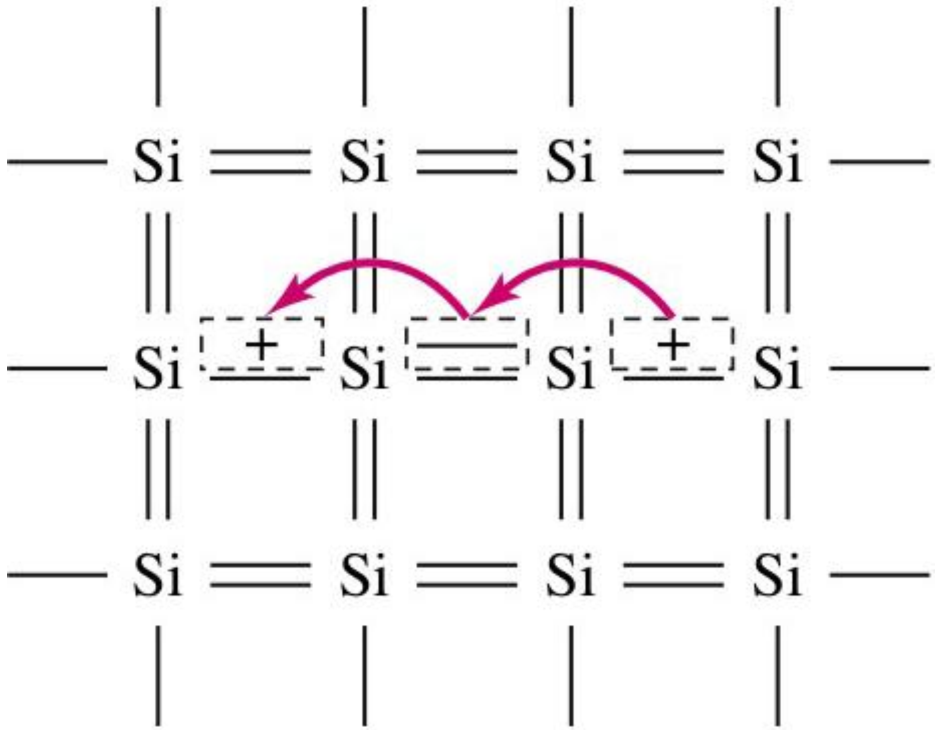


E_v – Maximum energy of a valence electron or hole

E_c – Minimum energy of a free electron

E_g – Energy required to break the covalent bond

Movement of Holes



A valence electron in a nearby bond can move to fill the broken bond, making it appear as if the 'hole' shifted locations.

Intrinsic Carrier Concentration

$$n_i = BT^{3/2} e^{\frac{-E_g}{2kT}}$$

B – coefficient related to specific semiconductor

T – temperature in Kelvin **0 °C = 273.15 K**

E_g – semiconductor bandgap energy

k – Boltzmann's constant

$$n_i(Si, 300K) = 1.5x10^{10}\,cm^{-3}$$

Extrinsic Semiconductors

- Impurity atoms replace some of the atoms in crystal
  - Column V atoms in Si are called donor impurities.
  - Column III in Si atoms are called acceptor impurities.

V·T·E

Periodic table

[hide]

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Alkali metals	Alkaline earth metals													Pnictogens	Chalcogens	Halogens	Noble gases
Period 1	Hydrogen 1 H																	Helium 2 He
2	Lithium 3 Li	Beryllium 4 Be											Boron 5 B	Carbon 6 C	Nitrogen 7 N	Oxygen 8 O	Fluorine 9 F	Neon 10 Ne
3	Sodium 11 Na	Magnesium 12 Mg											Aluminium 13 Al	Silicon 14 Si	Phos-phorus 15 P	Sulfur 16 S	Chlorine 17 Cl	Argon 18 Ar
4	Potassium 19 K	Calcium 20 Ca	Scandium 21 Sc	Titanium 22 Ti	Vanadium 23 V	Chromium 24 Cr	Manganese 25 Mn	Iron 26 Fe	Cobalt 27 Co	Nickel 28 Ni	Copper 29 Cu	Zinc 30 Zn	Gallium 31 Ga	Germanium 32 Ge	Arsenic 33 As	Selenium 34 Se	Bromine 35 Br	Krypton 36 Kr
5	Rubidium 37 Rb	Strontium 38 Sr	Yttrium 39 Y	Zirconium 40 Zr	Niobium 41 Nb	Molyb-denum 42 Mo	Technetium 43 Tc	Ruthenium 44 Ru	Rhodium 45 Rh	Palladium 46 Pd	Silver 47 Ag	Cadmium 48 Cd	Indium 49 In	Tin 50 Sn	Antimony 51 Sb	Tellurium 52 Te	Iodine 53 I	Xenon 54 Xe
6	Caesium 55 Cs	Barium 56 Ba	*	Hafnium 72 Hf	Tantalum 73 Ta	Tungsten 74 W	Rhenium 75 Re	Osmium 76 Os	Iridium 77 Ir	Platinum 78 Pt	Gold 79 Au	Mercury 80 Hg	Thallium 81 Tl	Lead 82 Pb	Bismuth 83 Bi	Polonium 84 Po	Astatine 85 At	Radon 86 Rn
7	Francium 87 Fr	Radium 88 Ra	**	Ruther-fordium 104 Rf	Dubnium 105 Db	Sea-borgium 106 Sg	Bohrium 107 Bh	Hassium 108 Hs	Meitnerium 109 Mt	Darm-stadtium 110 Ds	Roent-genium 111 Rg	Coper-nicium 112 Cn	Ununtrium 113 Uut	Flerovium 114 Fl	Unun-pentium 115 Uup	Liver-morium 116 Lv	Unun-septium 117 Uus	Unun-octium 118 Uuo
		*	Lanthanum 57 La	Cerium 58 Ce	Praseo-dymium 59 Pr	Neo-dymium 60 Nd	Prome-thium 61 Pm	Samarium 62 Sm	Europium 63 Eu	Gadolinium 64 Gd	Terbium 65 Tb	Dysprosium 66 Dy	Holmium 67 Ho	Erbium 68 Er	Thulium 69 Tm	Ytterbium 70 Yb	Lutetium 71 Lu	
		**	Actinium 89 Ac	Thorium 90 Th	Protac-tinium 91 Pa	Uranium 92 U	Neptunium 93 Np	Plutonium 94 Pu	Americium 95 Am	Curium 96 Cm	Berkelium 97 Bk	Californium 98 Cf	Einsteinium 99 Es	Fermium 100 Fm	Mende-levium 101 Md	Nobelium 102 No	Lawren-cium 103 Lr	

Copper: transition metal; primordial; solid

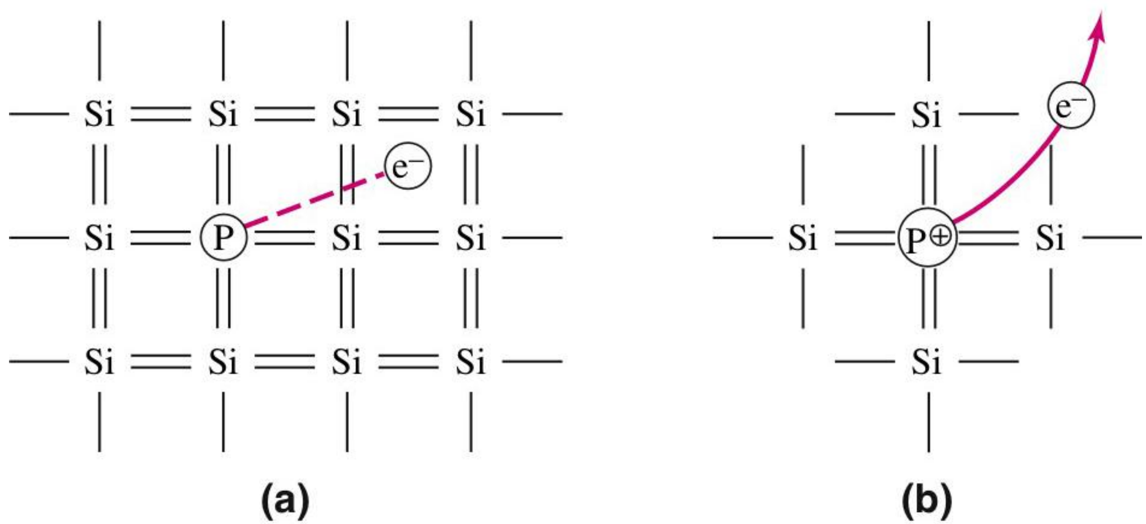
black=Solid | green=Liquid | red=Gas | grey=Unknown | **Color of the atomic number** shows state of matter (at 0 °C and 1 atm)

Primordial | From decay | Synthetic | **Border** shows natural occurrence of the element

Background color shows subcategory in the metal–nonmetal range:

Metal						Metalloid	Nonmetal			Unknown chemical properties
Alkali metal	Alkaline earth metal	Lanthanide	Actinide	Transition metal	Post-transition metal		Polyatomic nonmetal	Diatomic nonmetal	Noble gas	

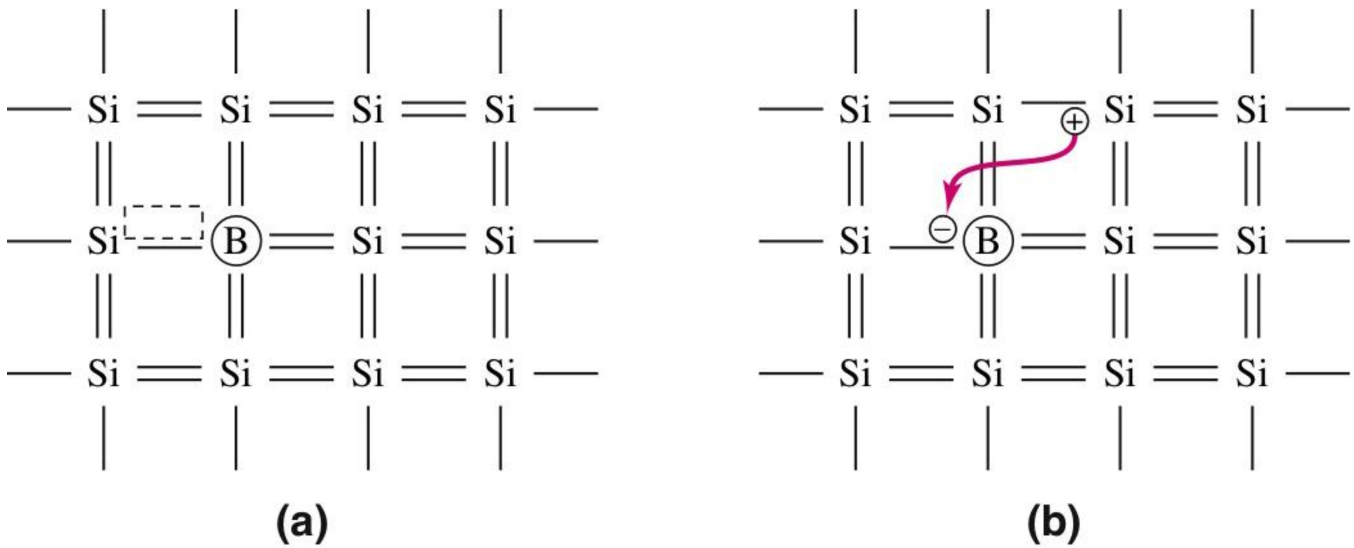
Phosphorous – Donor Impurity in Si



Phosphorous (P) replaces a Si atom and forms four covalent bonds with other Si atoms.

The **fifth** outer shell electron of P is easily freed to become a conduction band electron, adding to the number of electrons available to conduct current.

Boron – Acceptor Impurity in Si



Boron (B) replaces a Si atom and forms only **three** covalent bonds with other Si atoms.

The missing covalent bond is a hole, which can begin to move through the crystal when a valence electron from another Si atom is taken to form the fourth B-Si bond.

Electron and Hole Concentrations

n = electron concentration

p = hole concentration

$$n_i^2 = n \cdot p$$

n-type:

n = N_D, the donor concentration

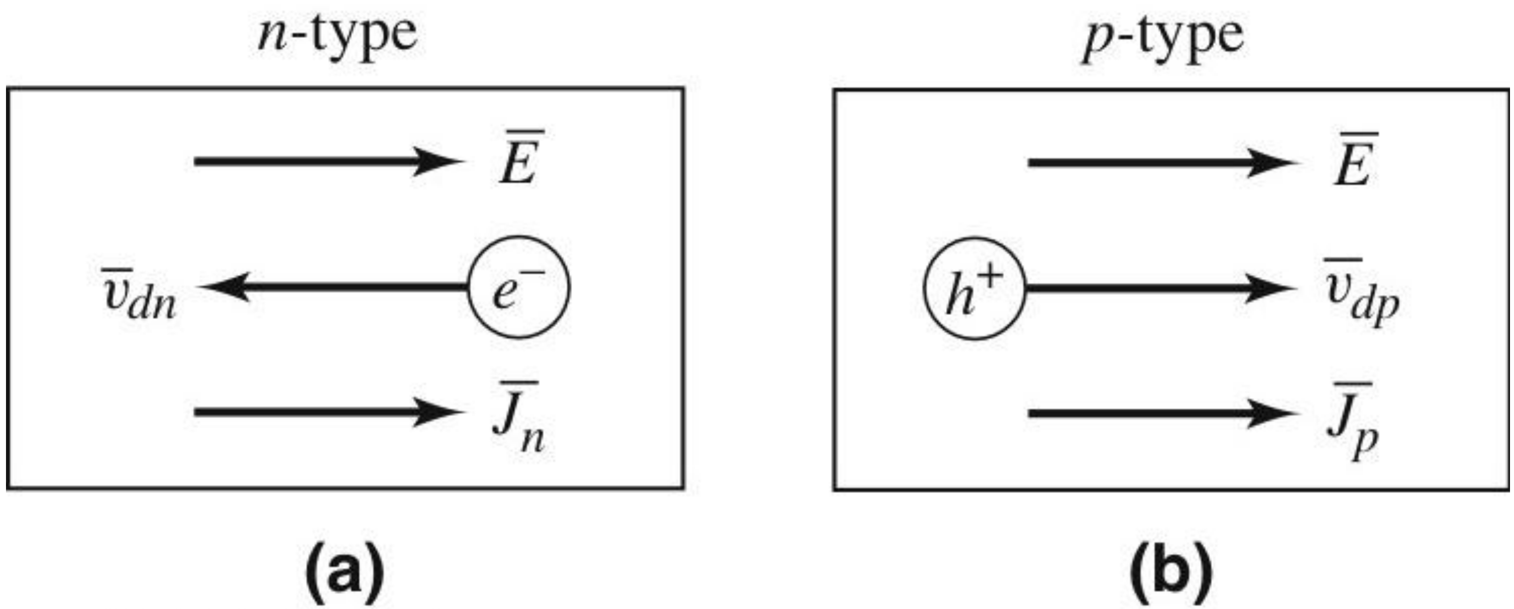
$$p = n_i^2 / N_D$$

p-type:

p = N_A, the acceptor concentration

$$n = n_i^2 / N_A$$

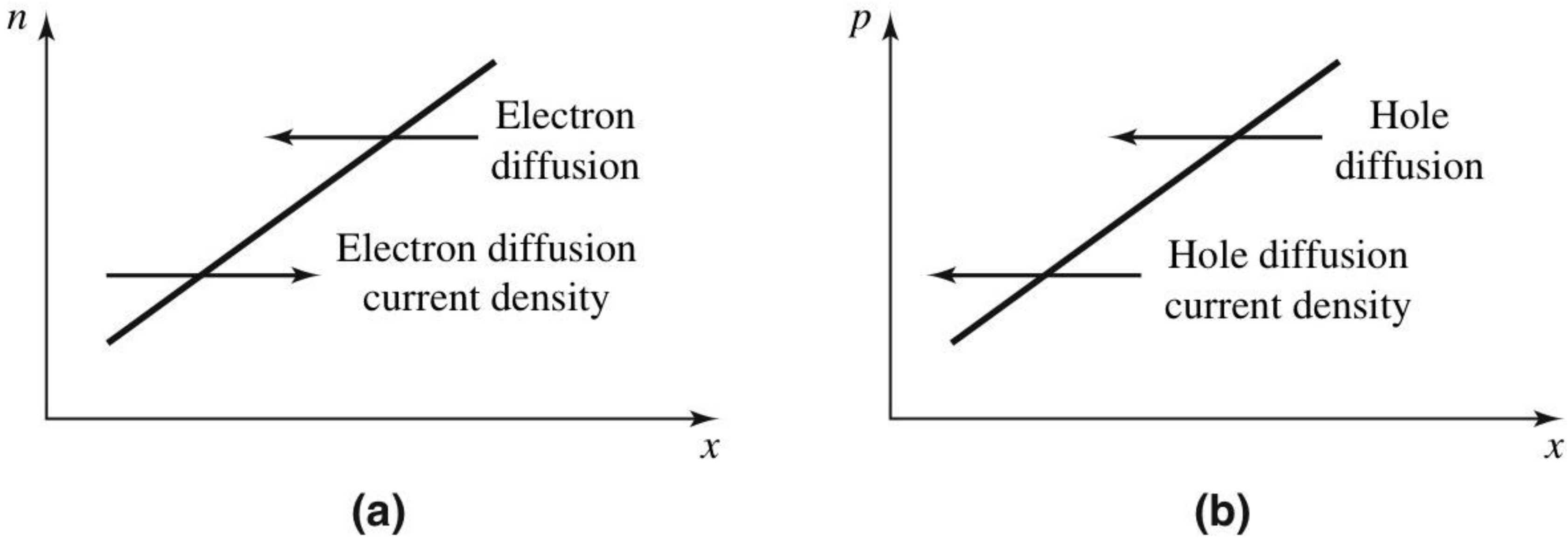
Drift Currents



Electrons and hole flow in opposite directions when under the influence of an electric field at different velocities.

The drift currents associated with the electrons and holes are in the same direction.

Diffusion Currents



Both electrons and holes flow from high concentration to low.

The diffusion current associated with the electrons flows in the opposite direction when compared to that of the holes.

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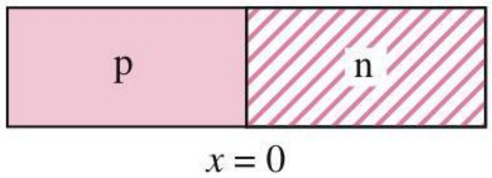
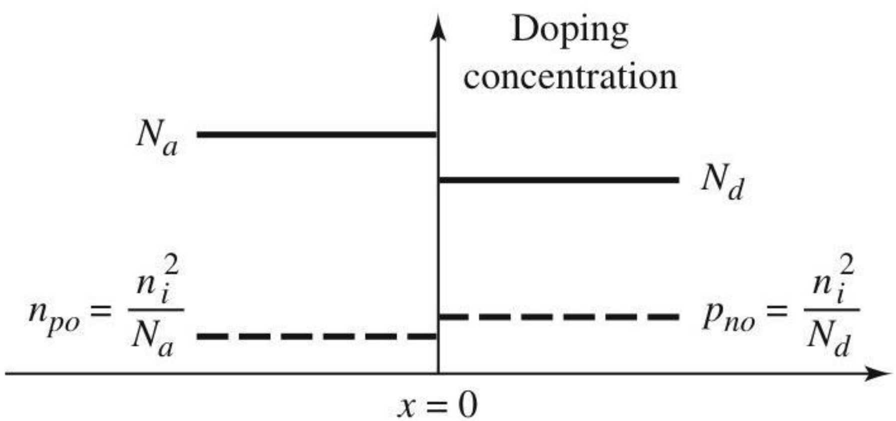
p-n Junctions

A simplified 1-D sketch of a p-n junction (a) has a doping profile (b).

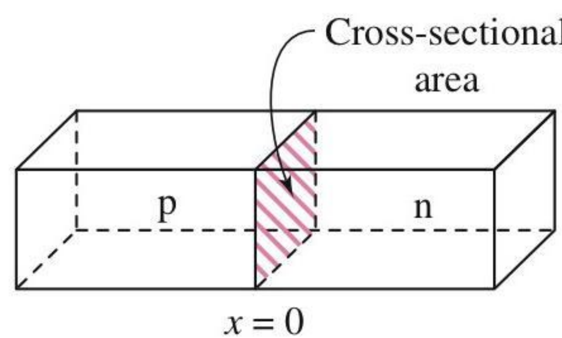
The 3-D representation (c) shows the cross sectional area of the junction.



(a)

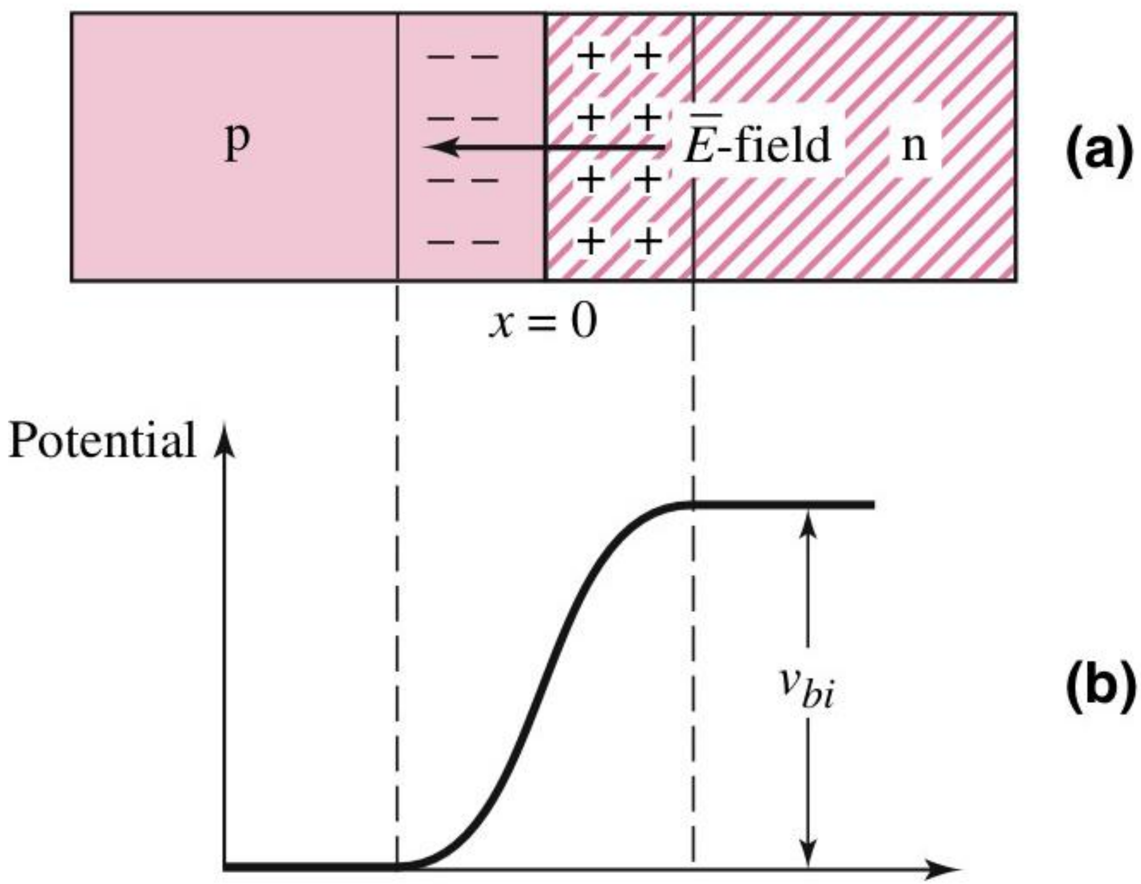


(b)



(c)

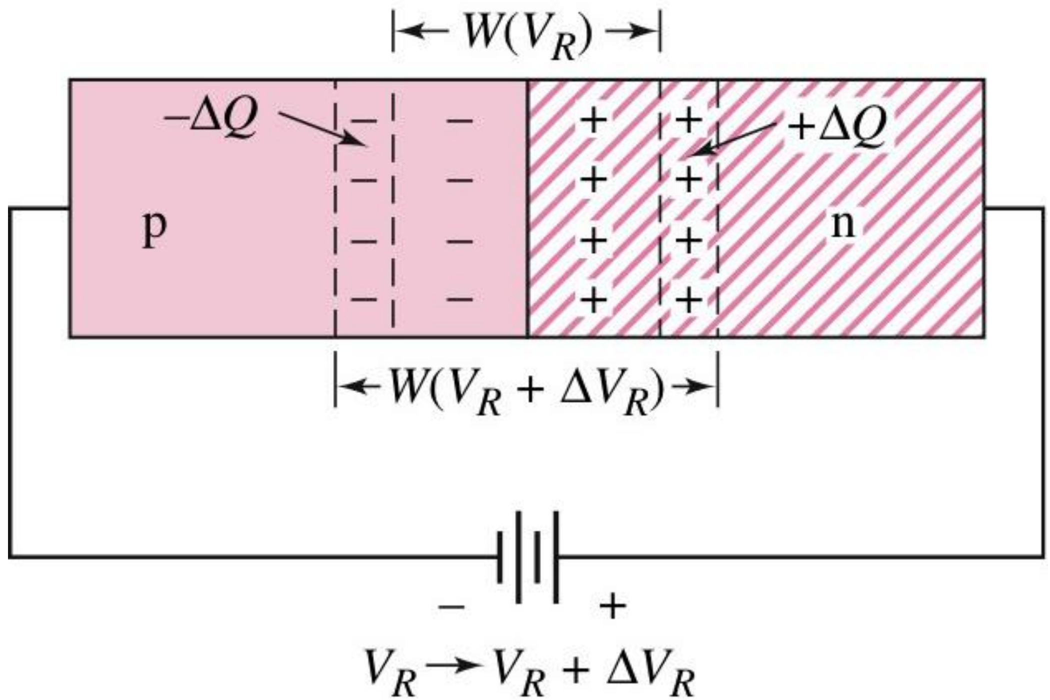
Built-in Potential



This movement of carriers creates a space charge or depletion region with an induced electric field near x = 0.

A potential voltage, v_{bi}, is developed across the junction.

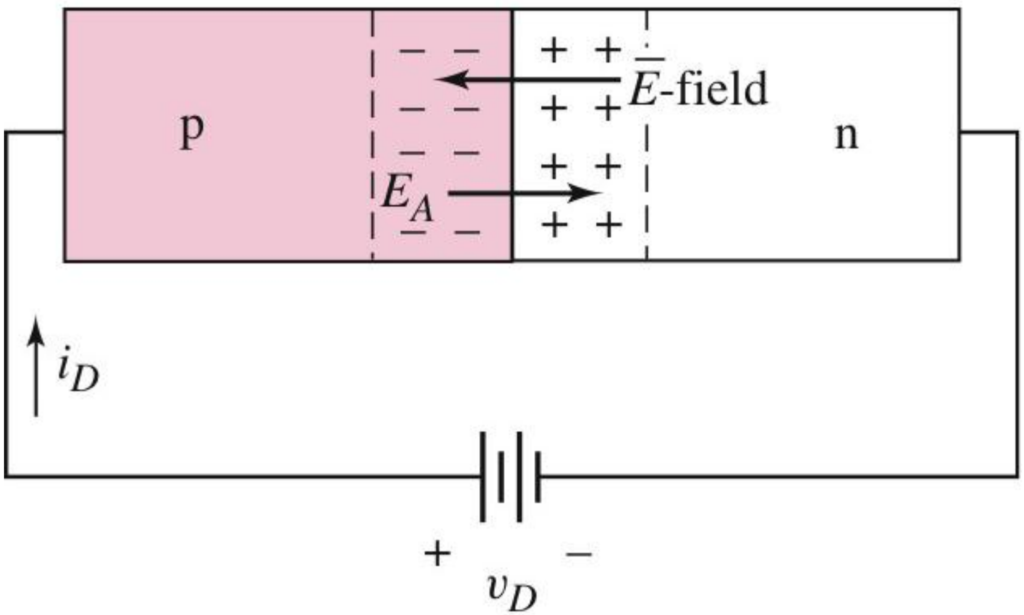
Reverse Bias



Increase in space-charge width, W, as V_R increases to $V_R+\Delta V_R$.

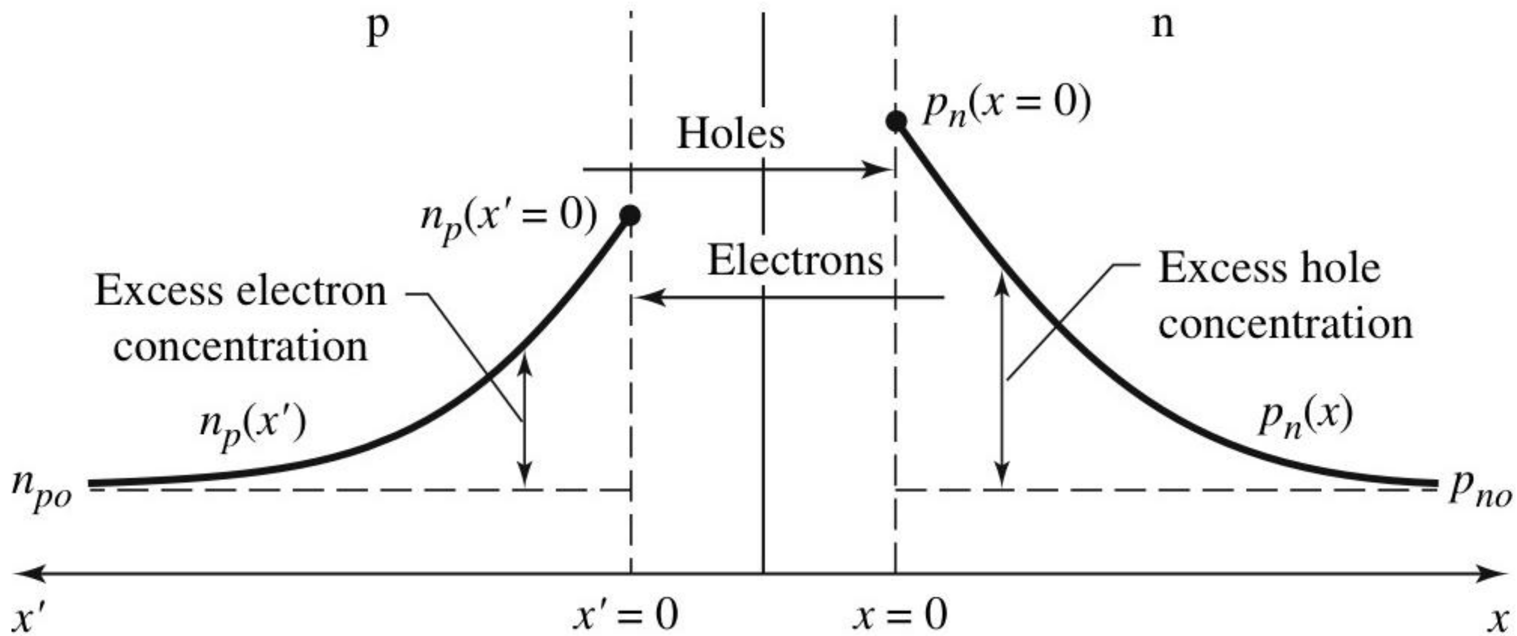
Creation of more fixed charges ($-\Delta Q$ and $+\Delta Q$) leads to junction capacitance.

Forward Biased p-n Junction



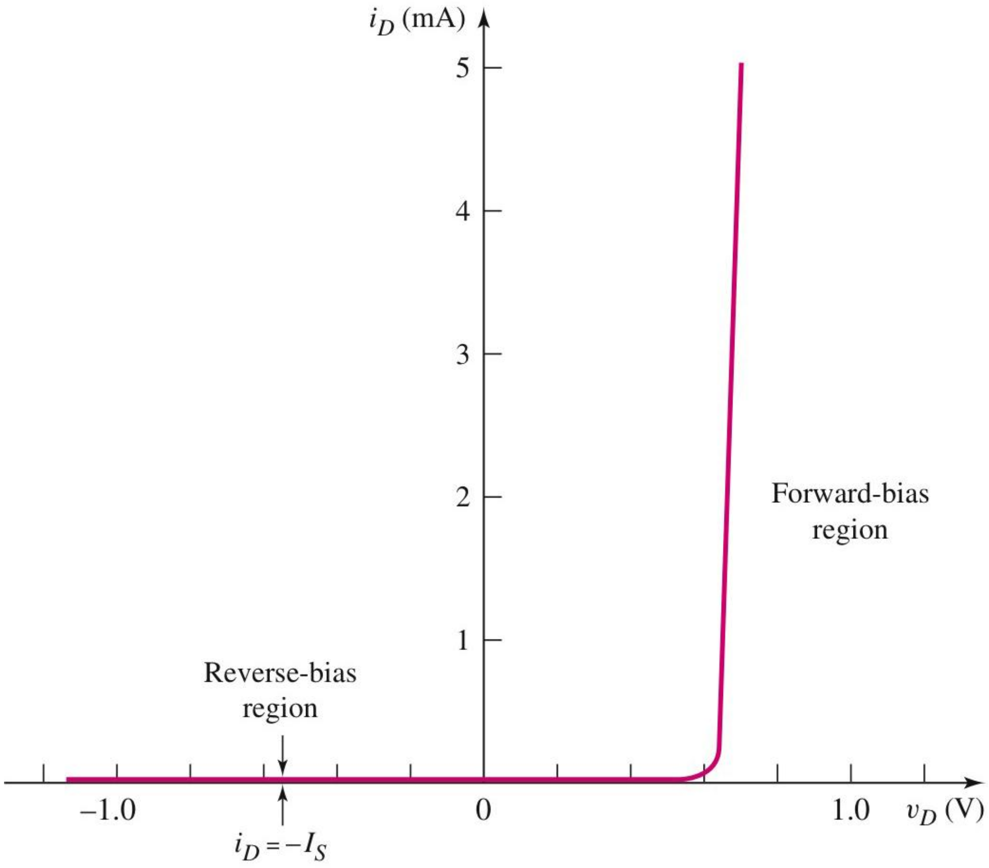
Applied voltage, v_D, induces an electric field, E_A, in the opposite direction as the original space-charge electric field, resulting in a smaller net electric field and smaller barrier between n and p regions.

Minority Carrier Concentrations



Gradients in minority carrier concentration generates diffusion currents in diode when forward biased.

Ideal Current-Voltage (I-V) Characteristics



The p-n junction only conducts significant current in the forward-bias region.

i_D is an exponential function in this region.

Essentially no current flows in reverse bias.

Ideal Diode Equation

A fit to the I-V characteristics of a diode yields the following equation, known as the ideal diode equation:

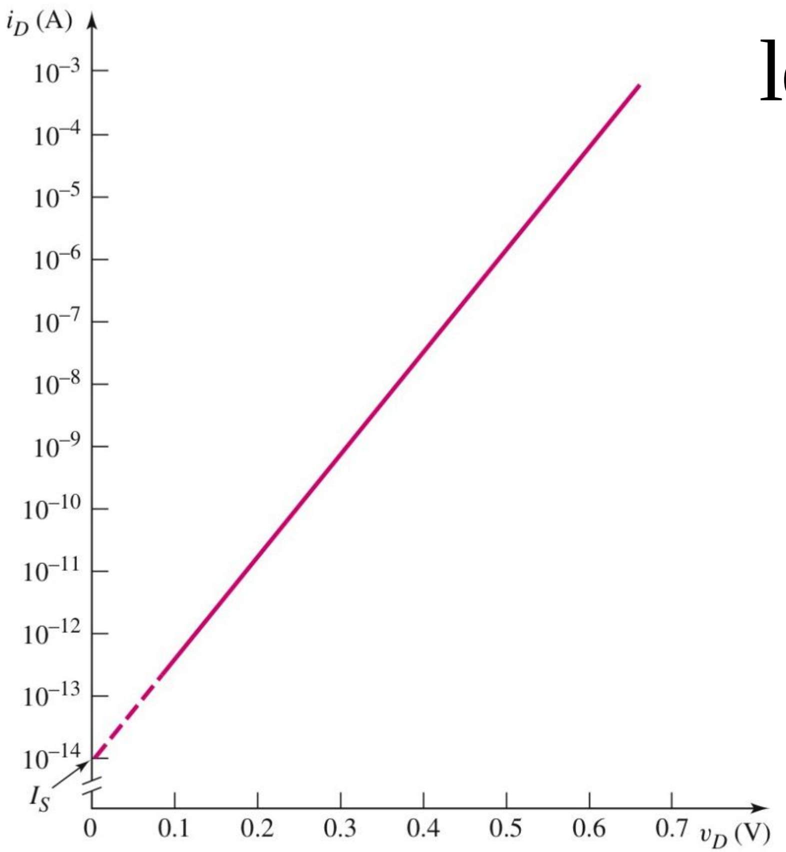
$$I_D = I_s\left(e^{\frac{qv_D}{nkT}} - 1\right)$$

kT/q is also known as the thermal voltage, V_T.

V_T = 25.9 mV when T = 300K, room temperature.

$$I_D = I_s\left(e^{\frac{v_D}{V_T}} - 1\right)$$

Ideal Diode Equation



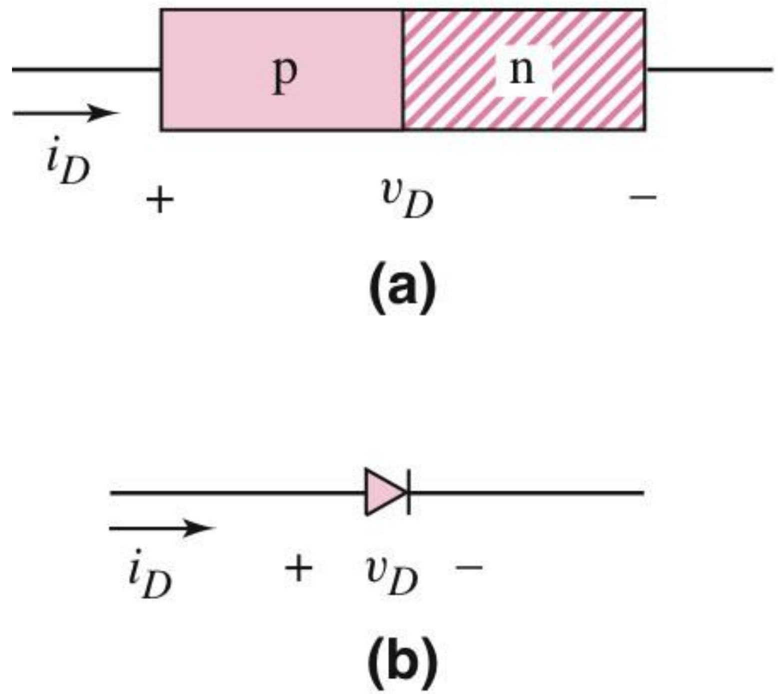
$$\log(i_D) \approx \frac{\log e}{nV_T} v_D + \log(I_s)$$

The y intercept is equal to I_S.

The slope is proportional to 1/n.

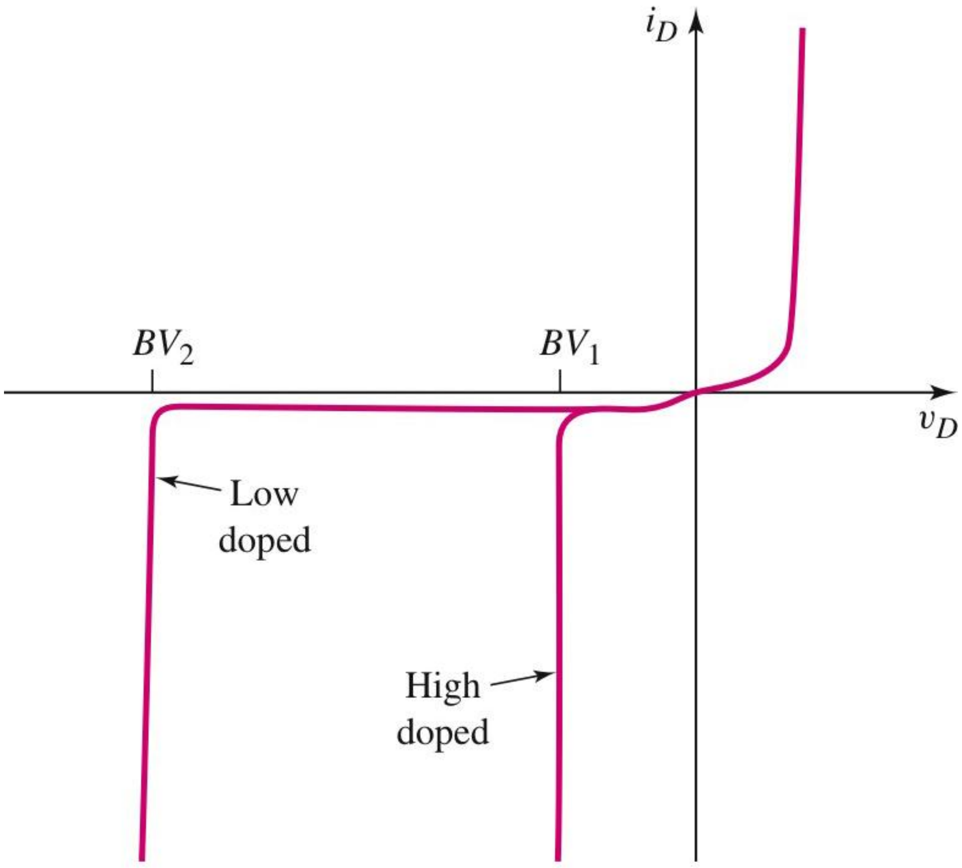
When n = 1, i_D increased by ~ one order of magnitude for every 60-mV increase in v_D.

Circuit Symbol



Conventional current direction and polarity of voltage drop is shown

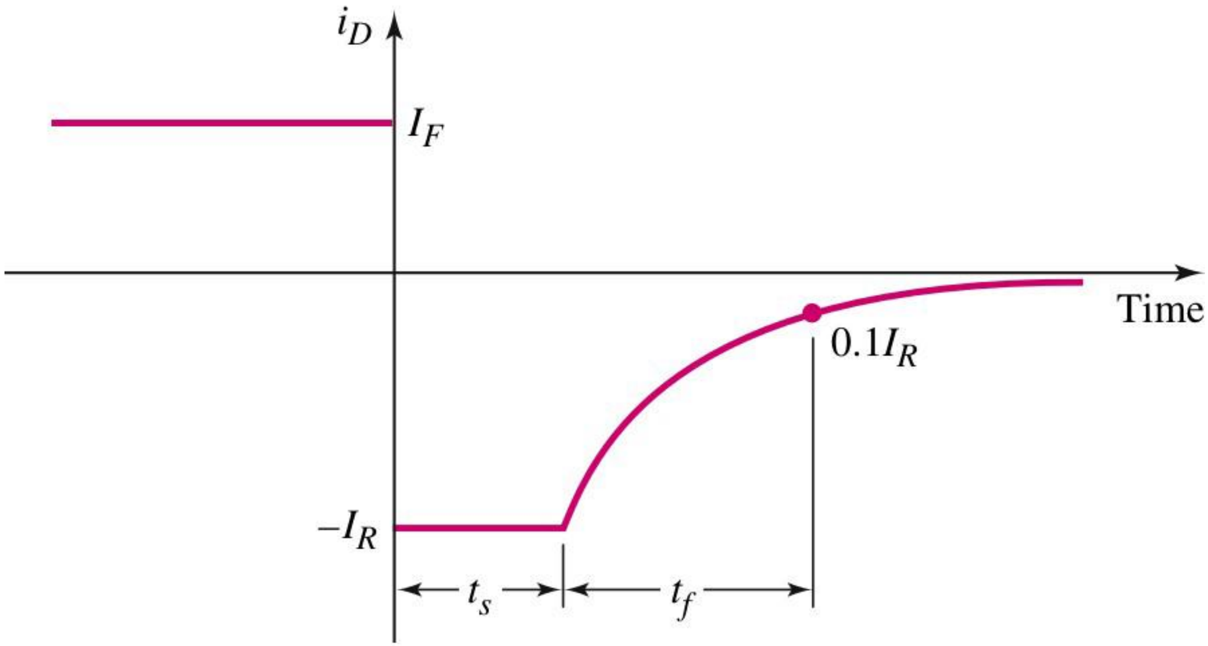
Breakdown Voltage



The magnitude of the breakdown voltage (BV) is smaller for heavily doped diodes as compared to more lightly doped diodes.

Current through a diode increases rapidly once breakdown has occurred.

Transient Response



Short reverse-going current pulse flows when the diode is switched from forward bias to zero or reverse bias as the excess minority carriers are removed.

It is composed of a storage time, t_s, and a fall time, t_f.

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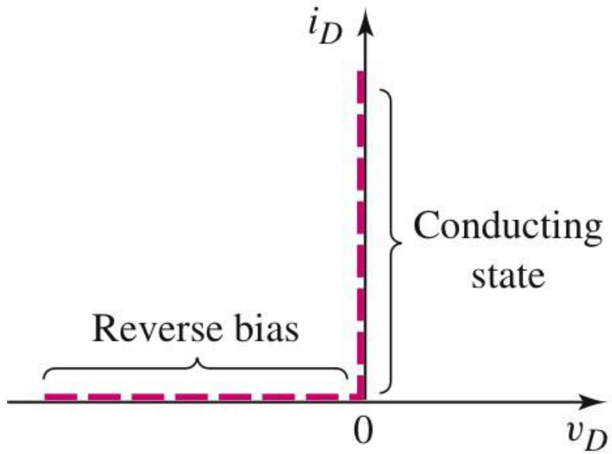
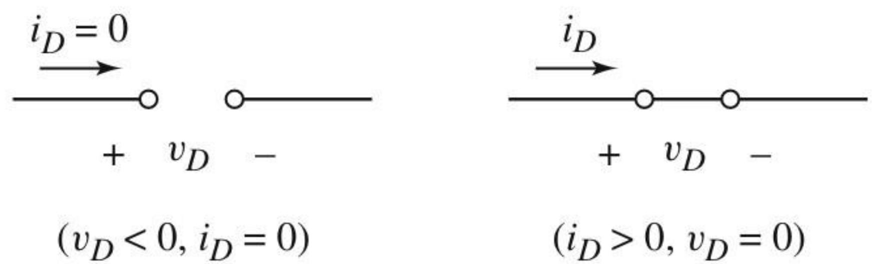
dc Model of Ideal Diode



(a)

Equivalent Circuits



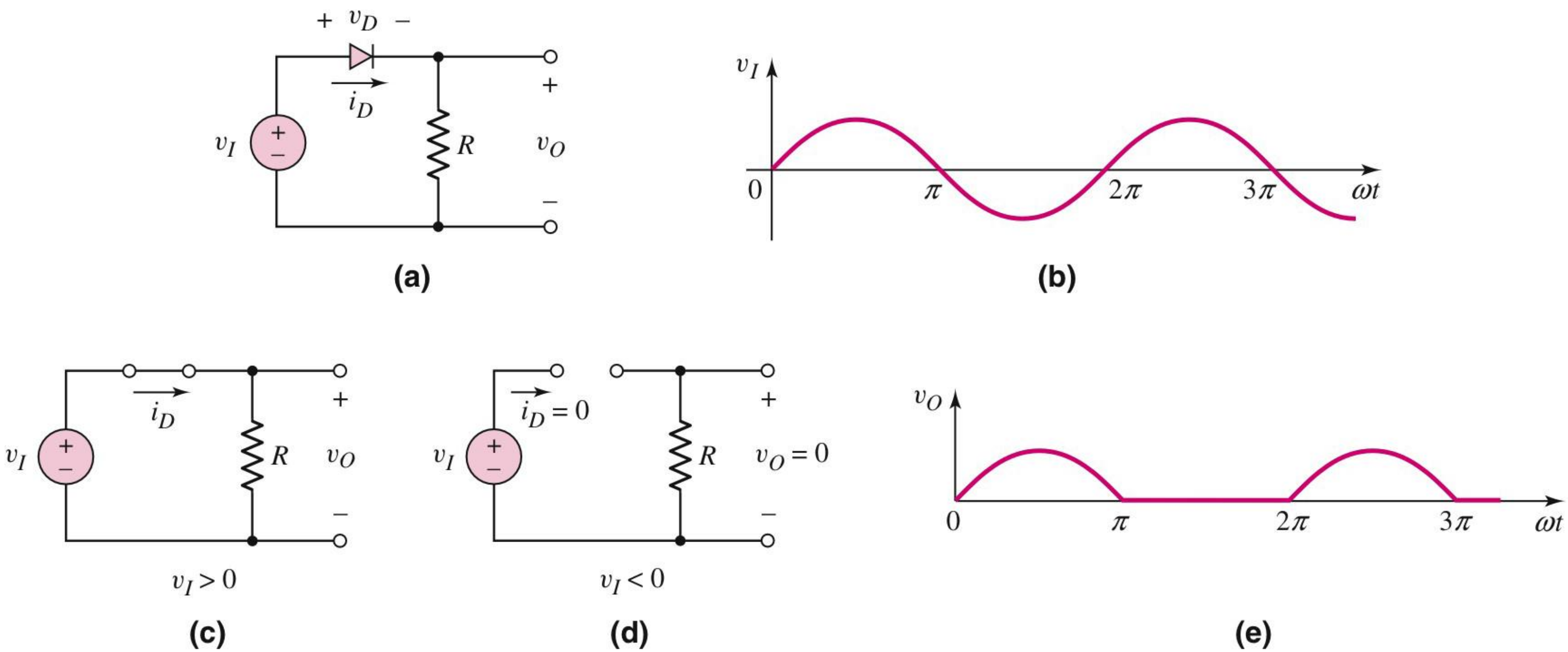
(b) (c)

Assumes $v_{bi} = 0$.

No current flows when reverse biased (b).

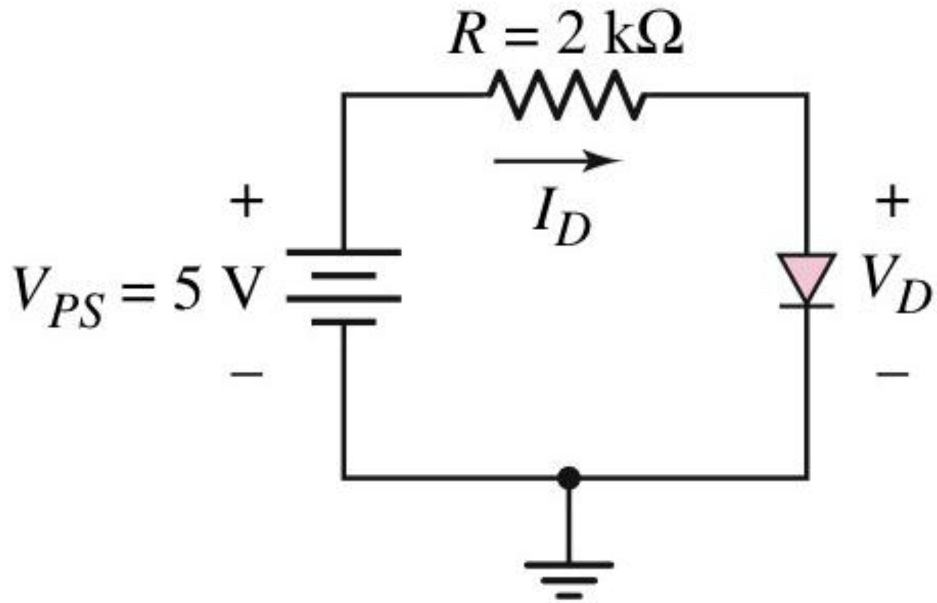
No internal resistance to limit current when forward biased (c).

Half-Wave Diode Rectifier



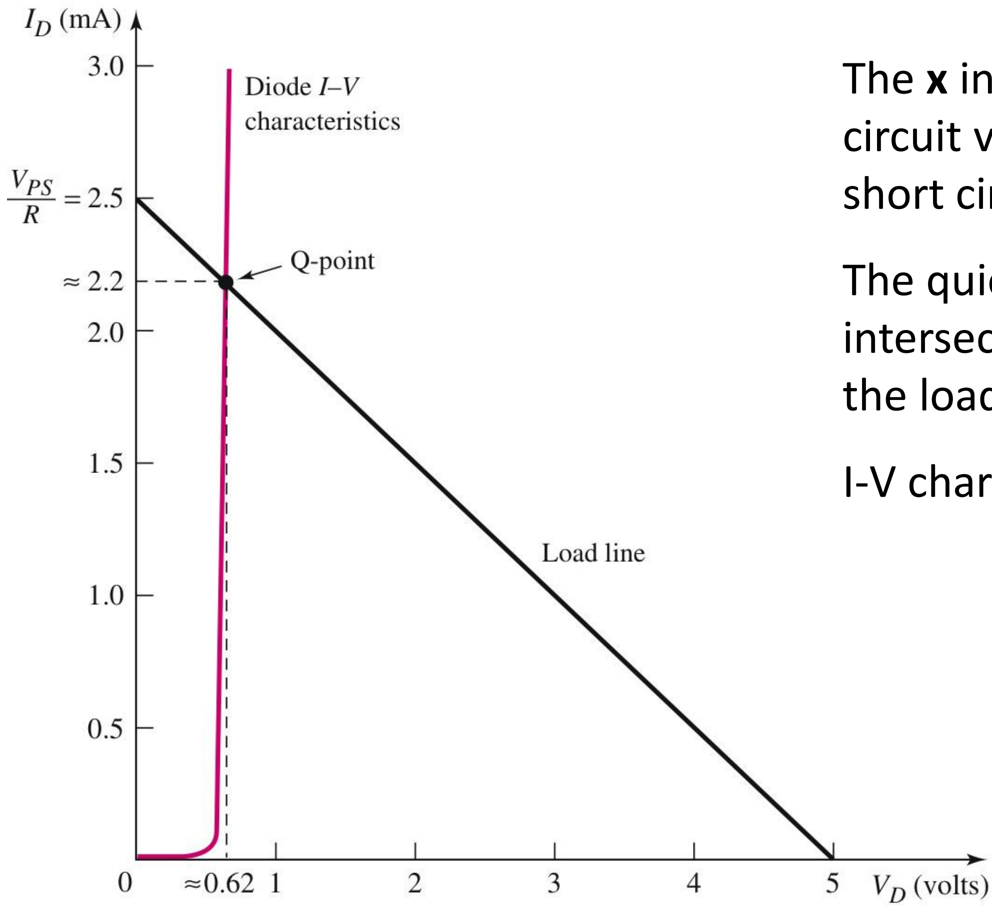
Diode only allows current to flow through the resistor when $v_I \geq 0$V. Forward-bias equivalent circuit is used to determine v_O under this condition.

Graphical Analysis Technique



Simple diode circuit where I_D and V_D are not known.

Load Line Analysis

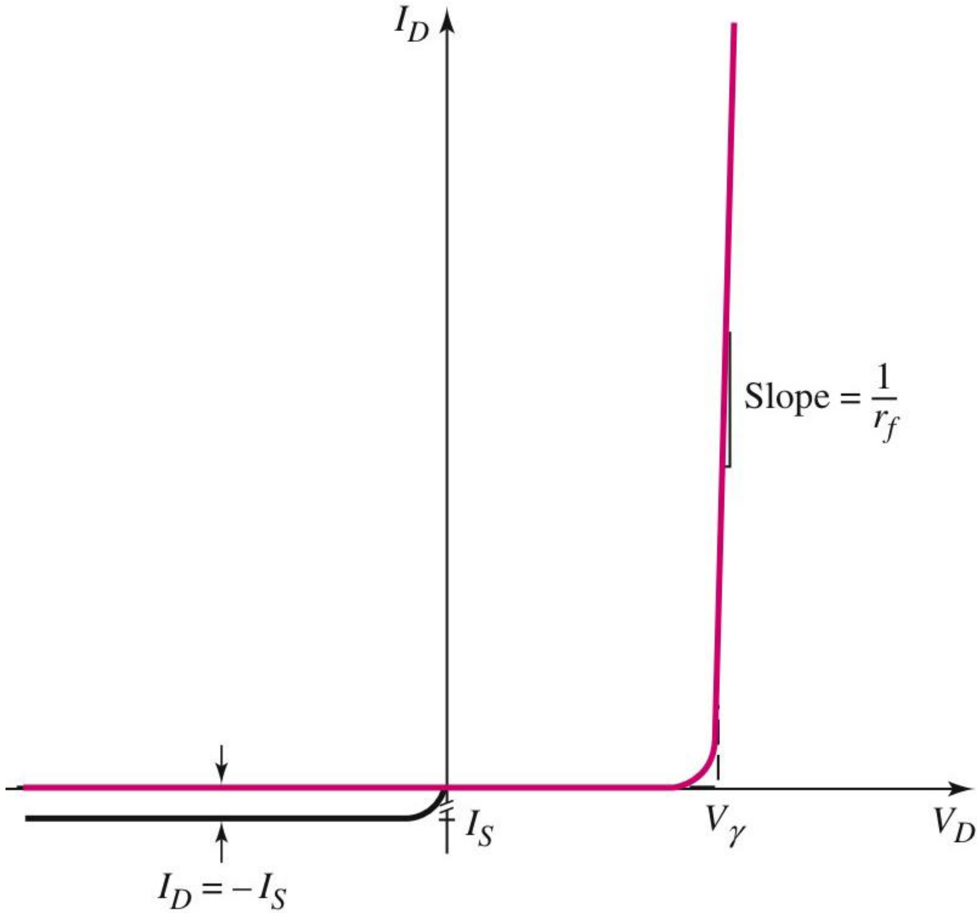


The **x** intercept of the load line is the open circuit voltage and the **y** intercept is the short circuit current.

The quiescent point or Q-point is the intersection of diode I-V characteristic with the load line.

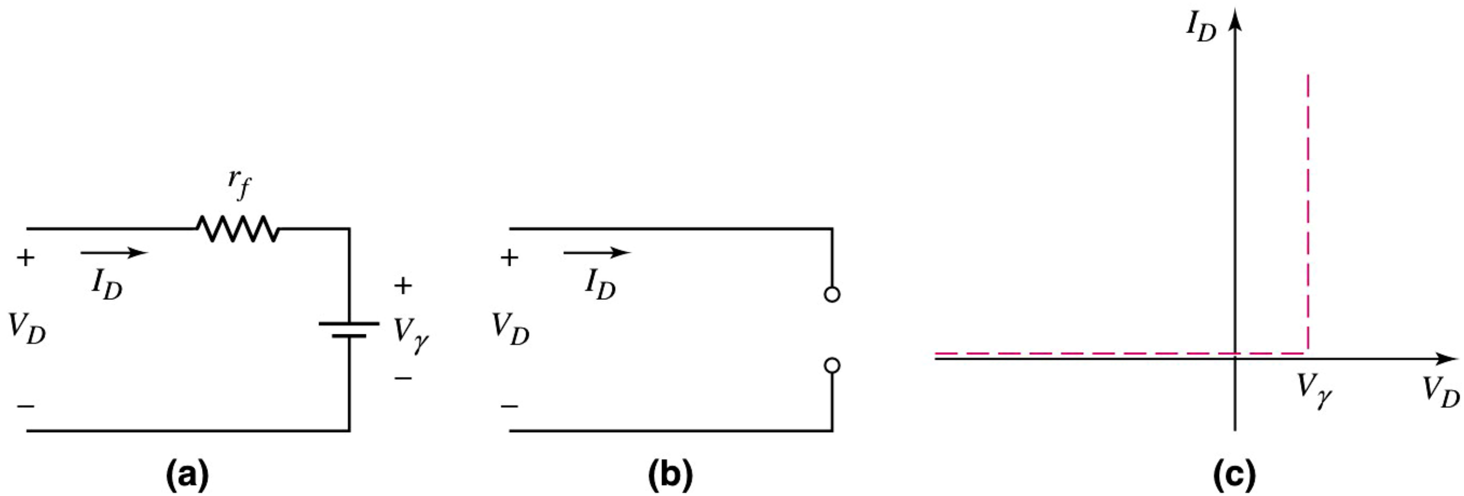
I-V characteristics of diode must be known.

Piecewise Linear Model



Two linear approximations are used to form piecewise linear model of diode.

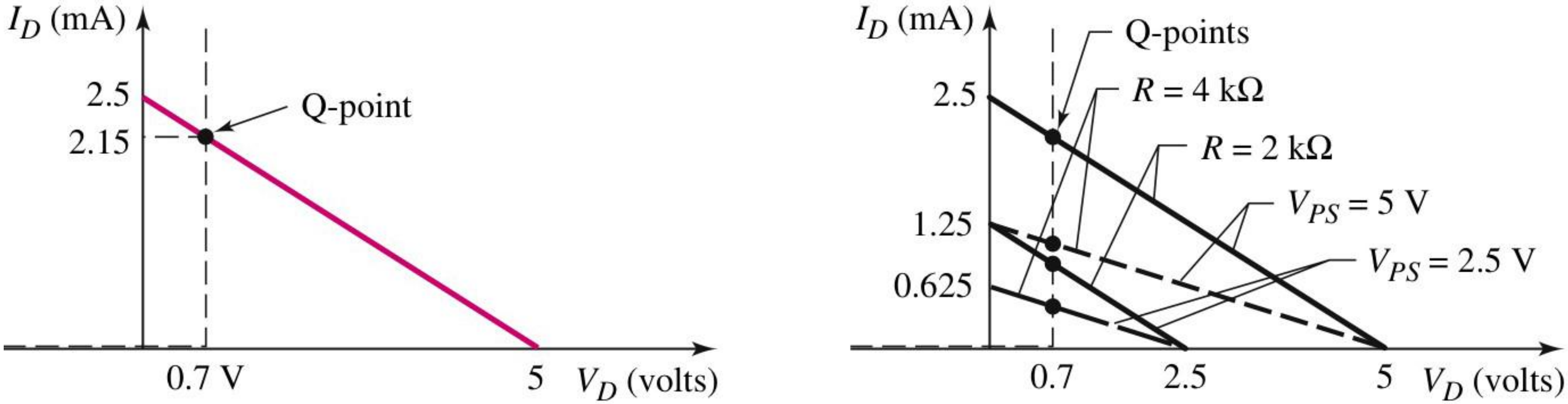
Diode Piecewise Equivalent Circuit



The diode is replaced by a battery with voltage, V_γ, with a a resistor, r_f, in series when in the 'on' condition (a) and is replaced by an open when in the 'off' condition, $V_D < V_\gamma$.

If $r_f = 0$, $V_D = V_\gamma$ when the diode is conducting.

Q-point

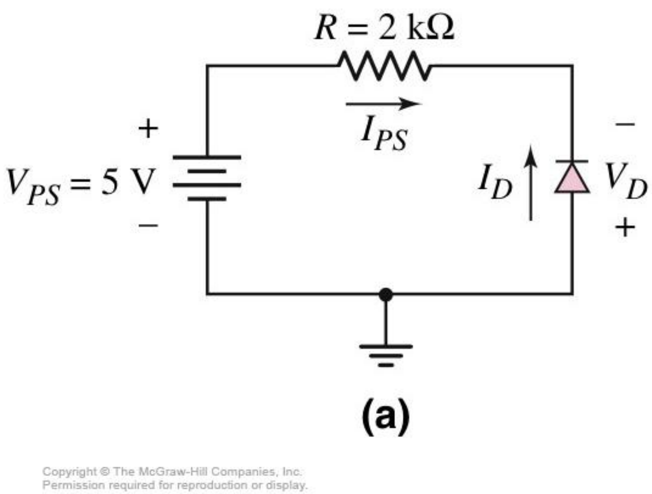


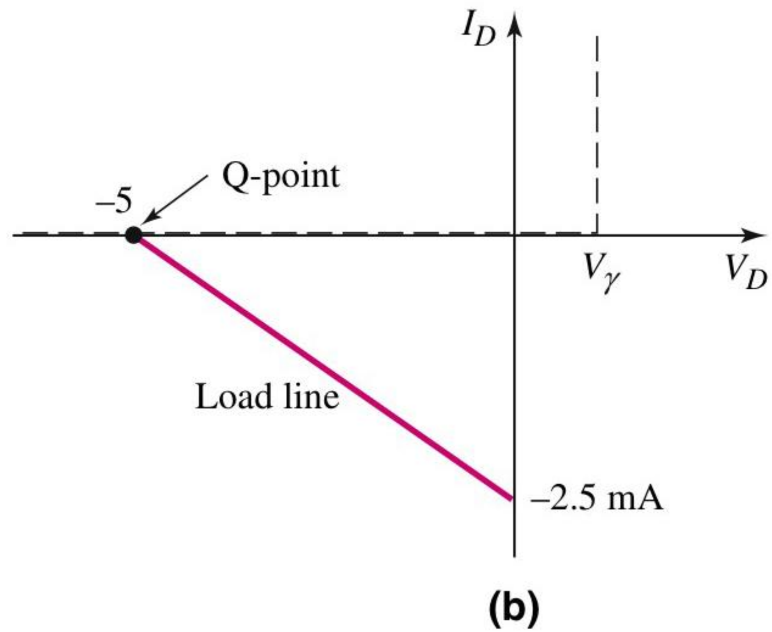
(a) **(b)**

The **x** intercept of the load line is the open circuit voltage and the **y** intercept is the short circuit current.

The Q-point is dependent on the power supply voltage and the resistance of the rest of the circuit as well as on the diode I-V characteristics.

Load Line: Reverse Biased Diode

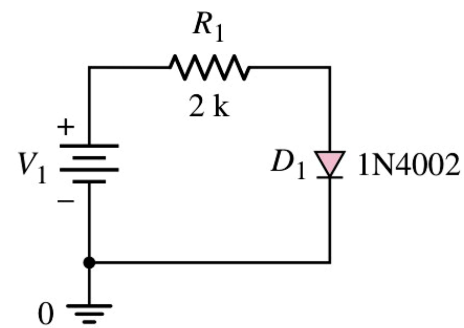




The Q-point is always $I_D = 0$ and V_D = the open circuit voltage when using the piecewise linear equivalent circuit.

PSpice Analysis

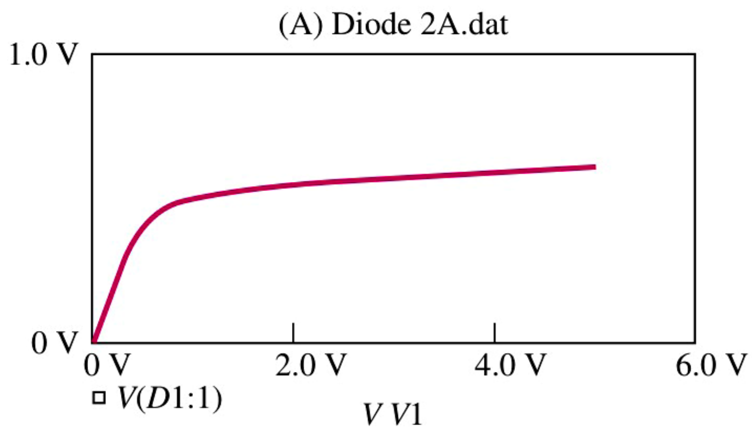
Circuit schematic



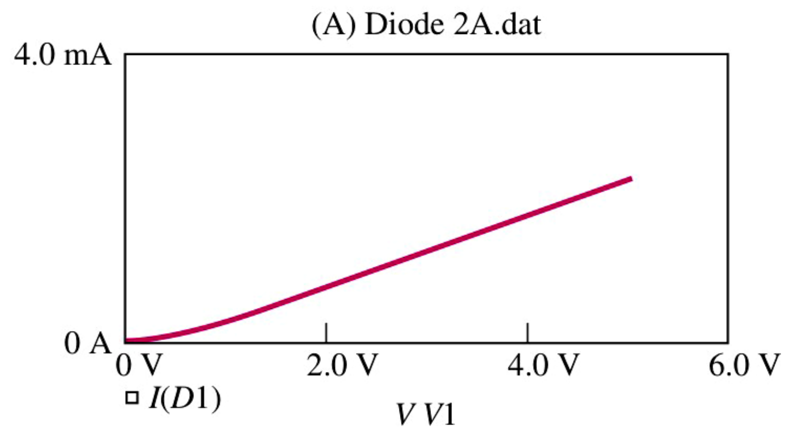
(a)

Diode voltage

Diode current



(b)



(c)

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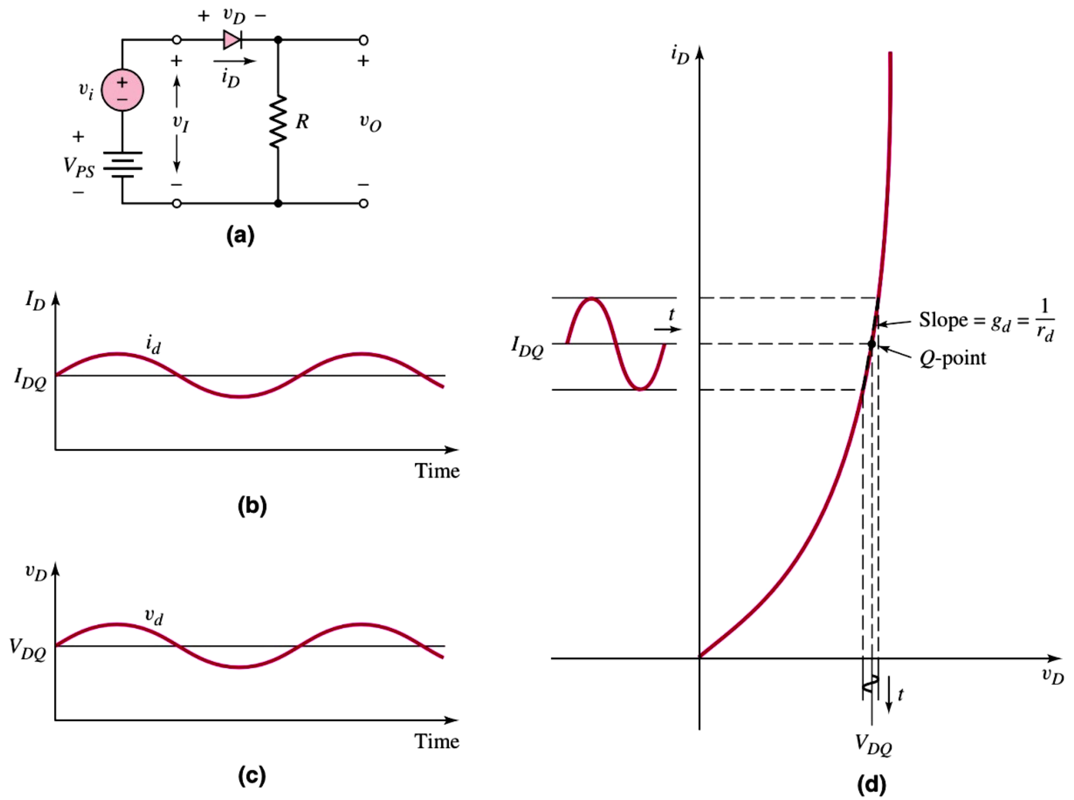
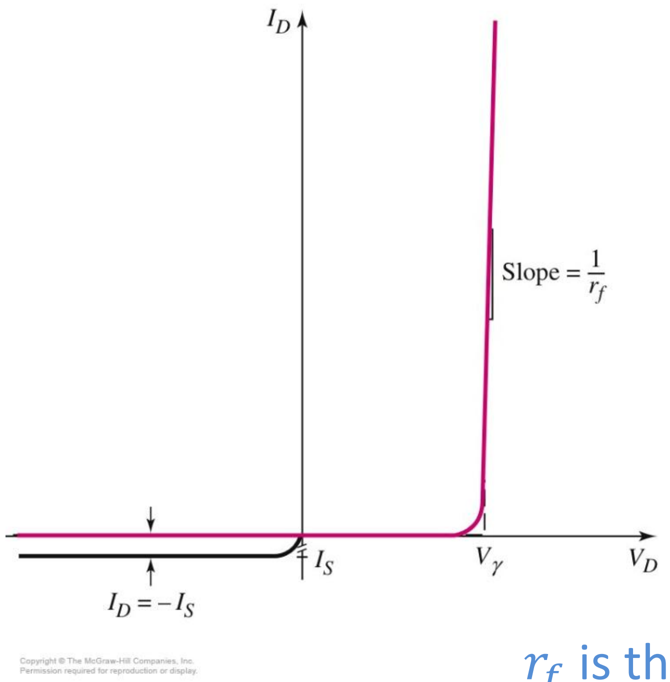
ac Circuit Analysis

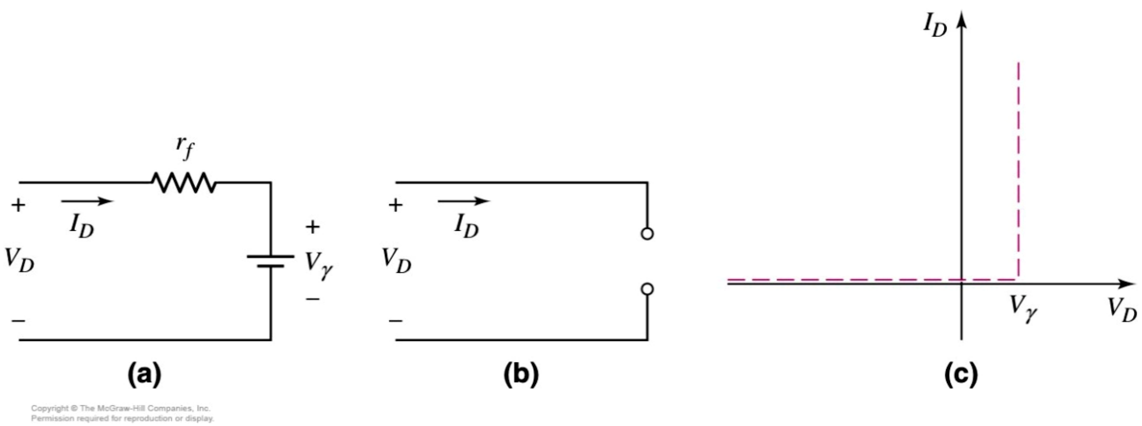


Combination of dc and sinusoidal input voltages modulate the operation of the diode about the Q-point.

Comparison

- Diode Piecewise Equivalent Circuit

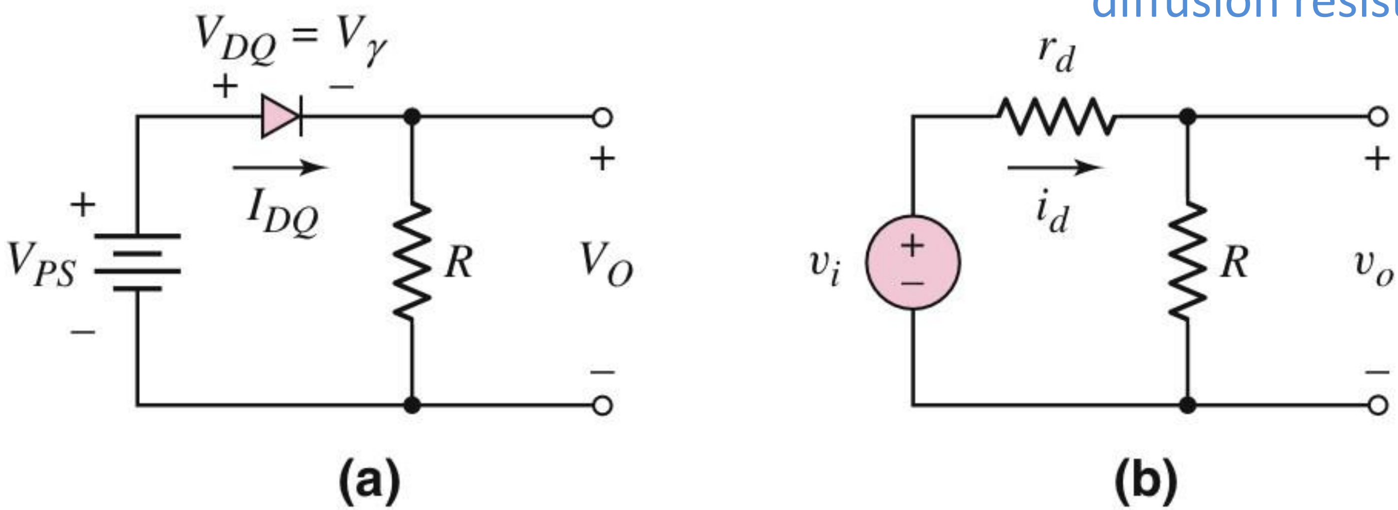




r_f is the forward diode resistance.
V_γ is the turn on voltage.

Equivalent Circuits

r_d is the small signal incremental resistance, or diffusion resistance.

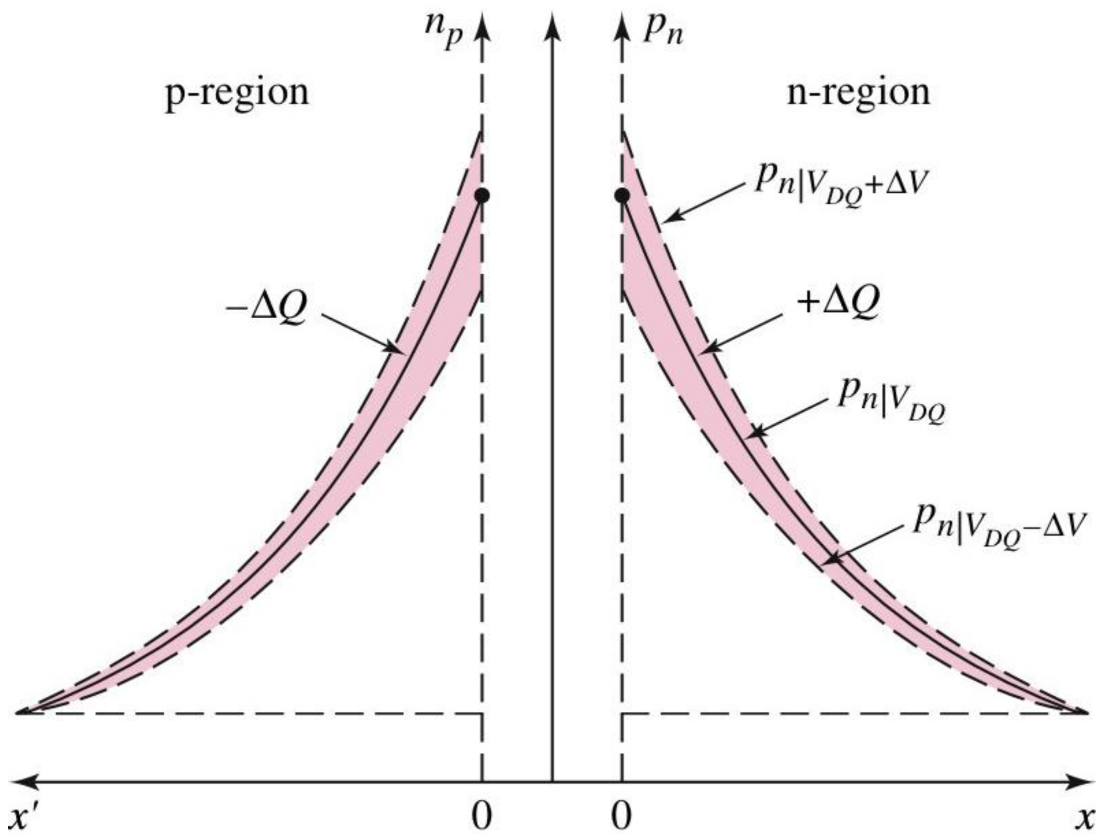


When ac signal is small, the dc operation can be decoupled from the ac operation.

First perform dc analysis using the dc equivalent circuit (a).

Then perform the ac analysis using the ac equivalent circuit (b).

Minority Carrier Concentration

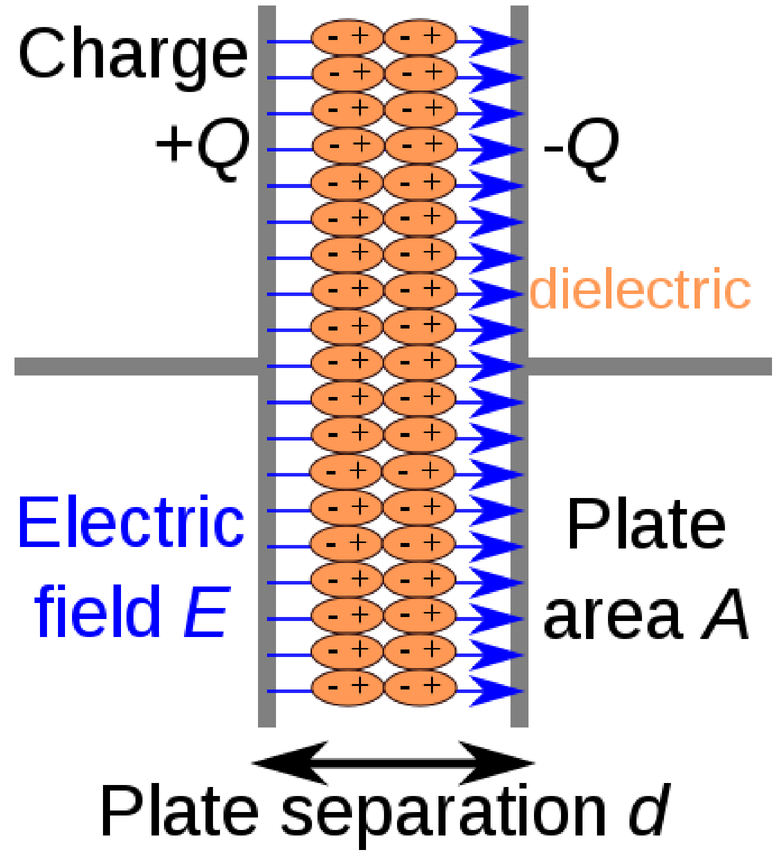


Time-varying excess charge leads to diffusion capacitance.

Capacitance

- An ideal capacitor is wholly characterized by a constant capacitance *C*, defined as the ratio of charge $\pm Q$ on each conductor to the voltage *V* between them:

$$C = \frac{Q}{V}$$

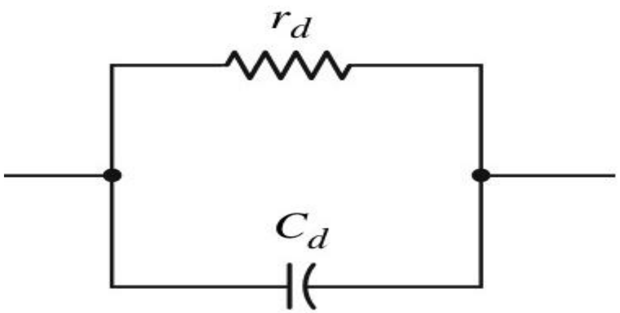


Capacitance

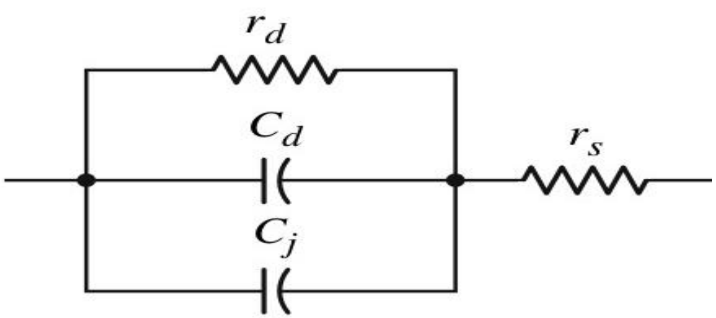
- Sometimes charge build-up affects the capacitor mechanically, causing its capacitance to vary. In this case, capacitance is defined in terms of incremental changes

$$C = \frac{\mathrm{d}Q}{\mathrm{d}V}$$

Small Signal Equivalent Model



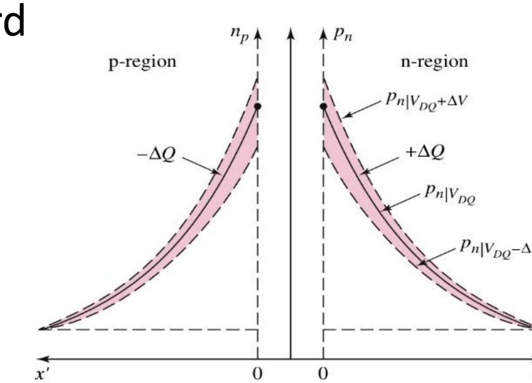
(a)



(b)

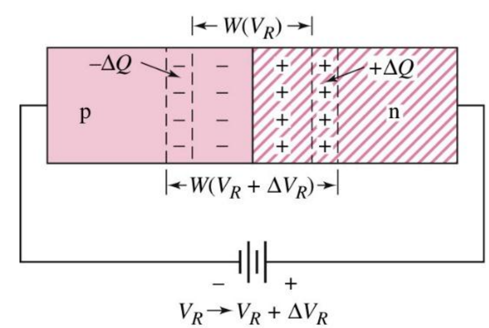
Simplified model, which can only be used when the diode is forward biased.

$$C_d = \frac{dQ}{dV_D}$$



Complete model

$$C_j = C_{j0}\left(1 + \frac{V_R}{V_{bi}}\right)^{-1/2}$$



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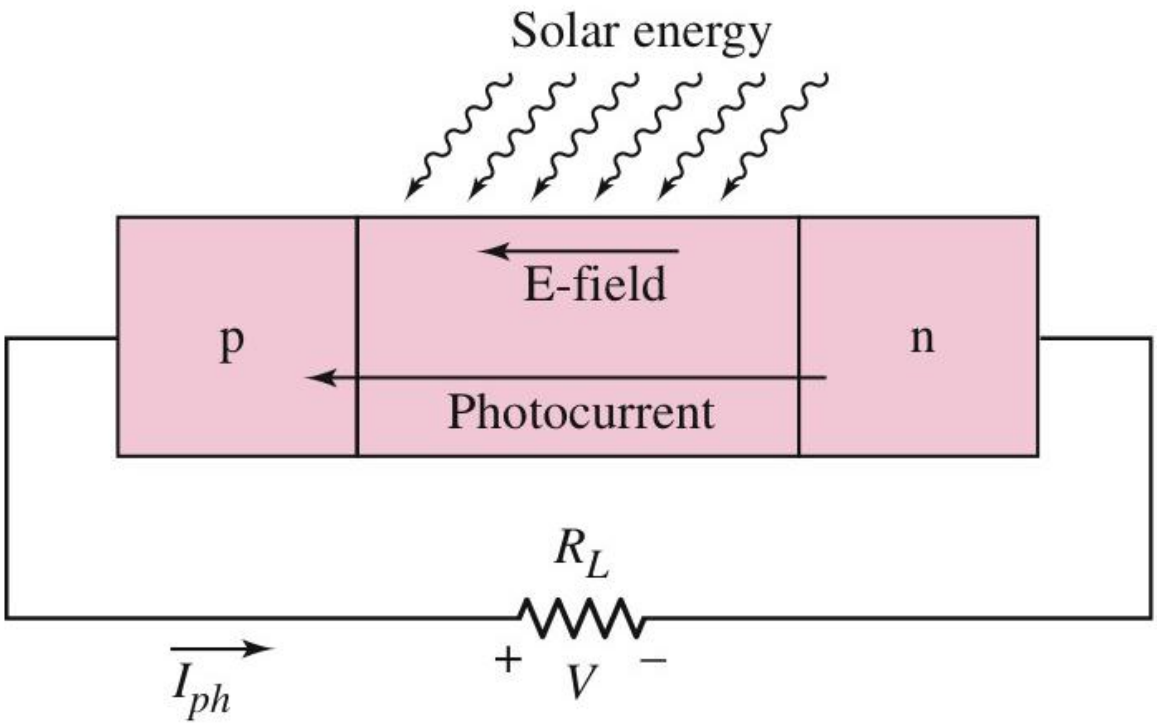
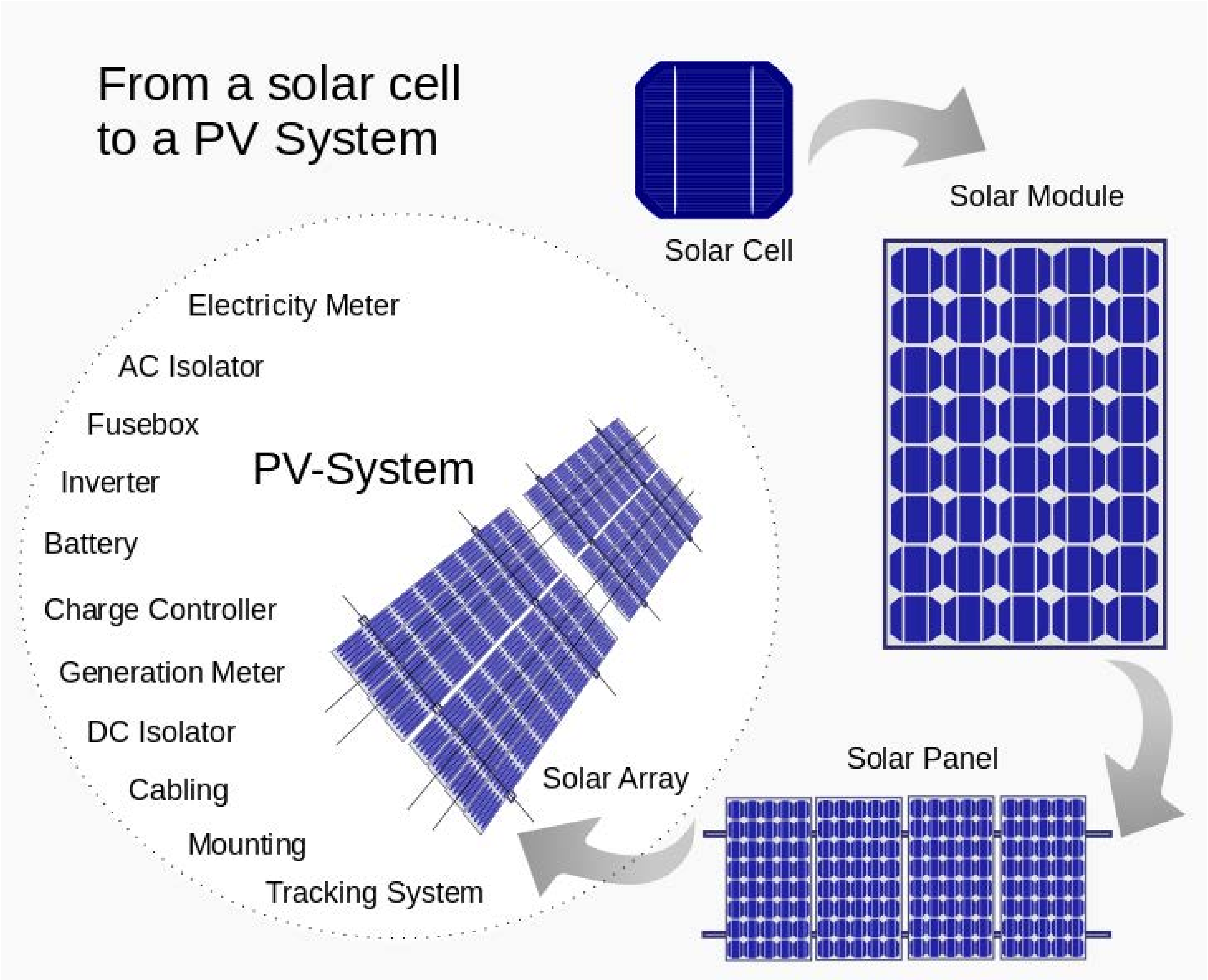
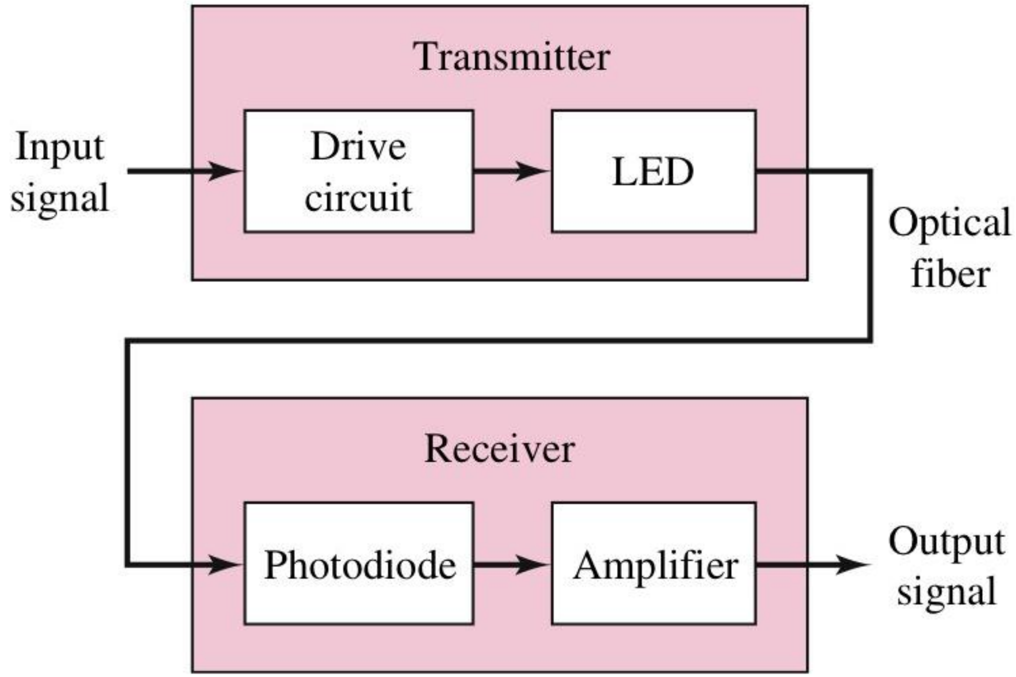
Photogenerated Current



When the energy of the photons is greater than E_g, the photon's energy can be used to break covalent bonds and generate an equal number of electrons and holes to the number of photons absorbed.

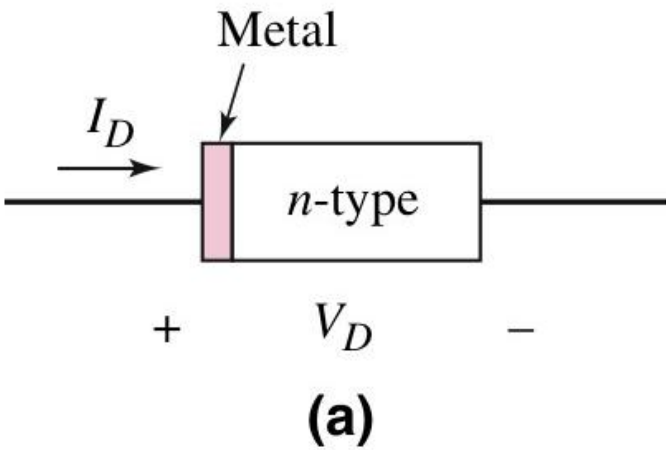

From a solar cell
to a PV System
Solar Cell
Solar Module
Solar Panel
Solar Array
PV-System
Electricity Meter
AC Isolator
Fusebox
Inverter
Battery
Charge Controller
Generation Meter
DC Isolator
Cabling
Mounting
Tracking System

Optical Transmission System

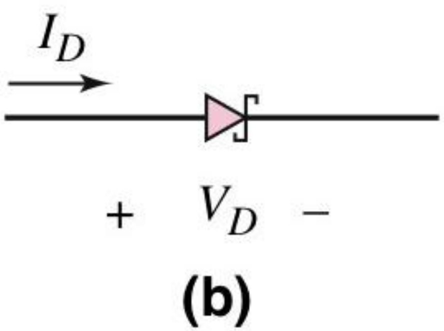


LED (**L**ight **E**mitting **Diode**) and photodiode are p-n junctions.

Schottky Barrier Diode



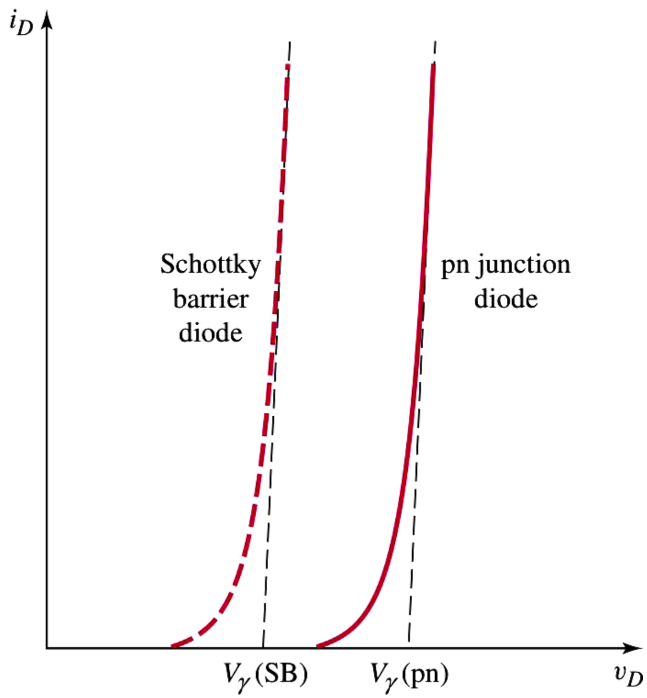
A metal layer replaces the p region of the diode.



Circuit symbol showing conventional current direction of current and polarity of voltage drop.

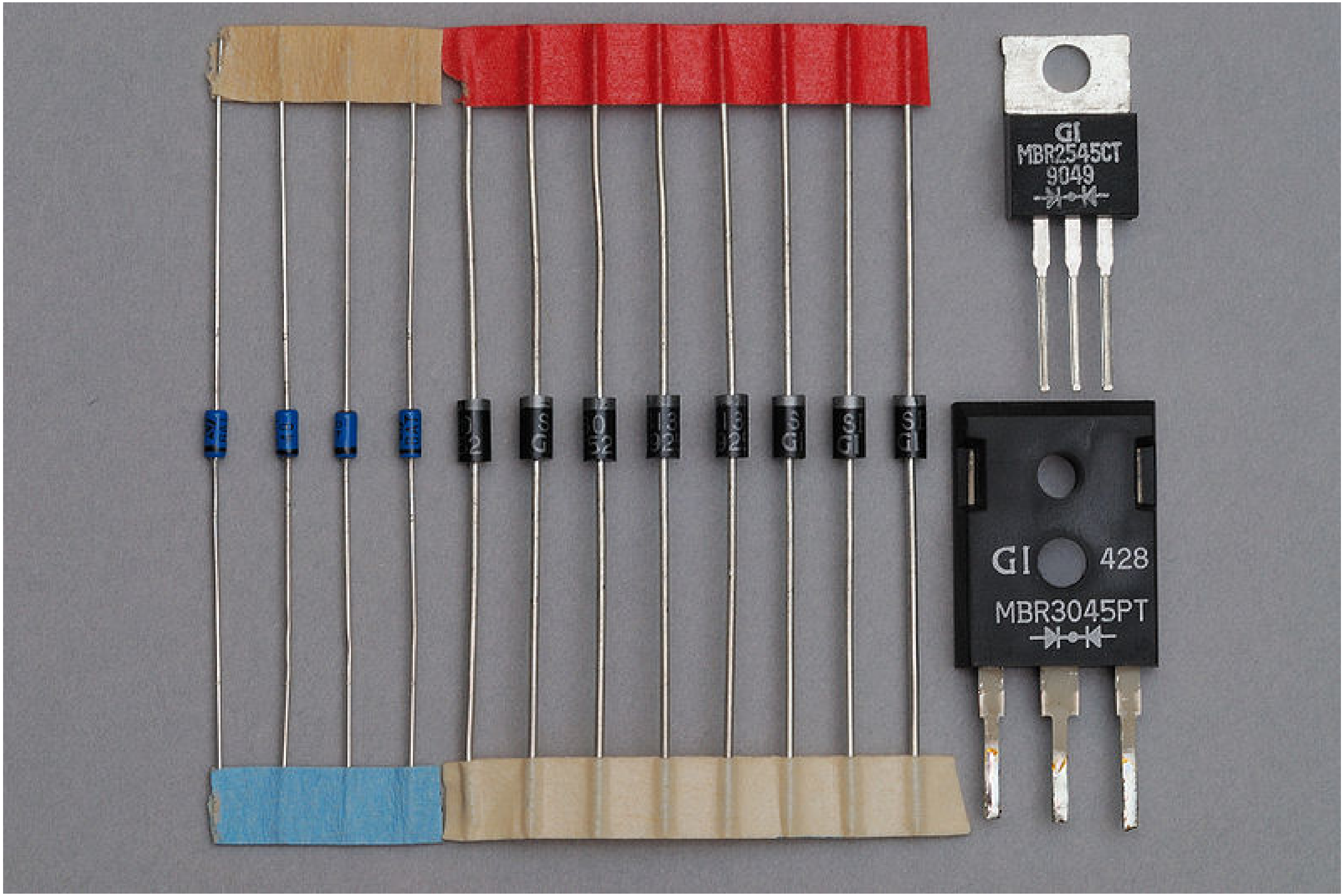
Comparison of I-V Characteristics:

Forward Bias



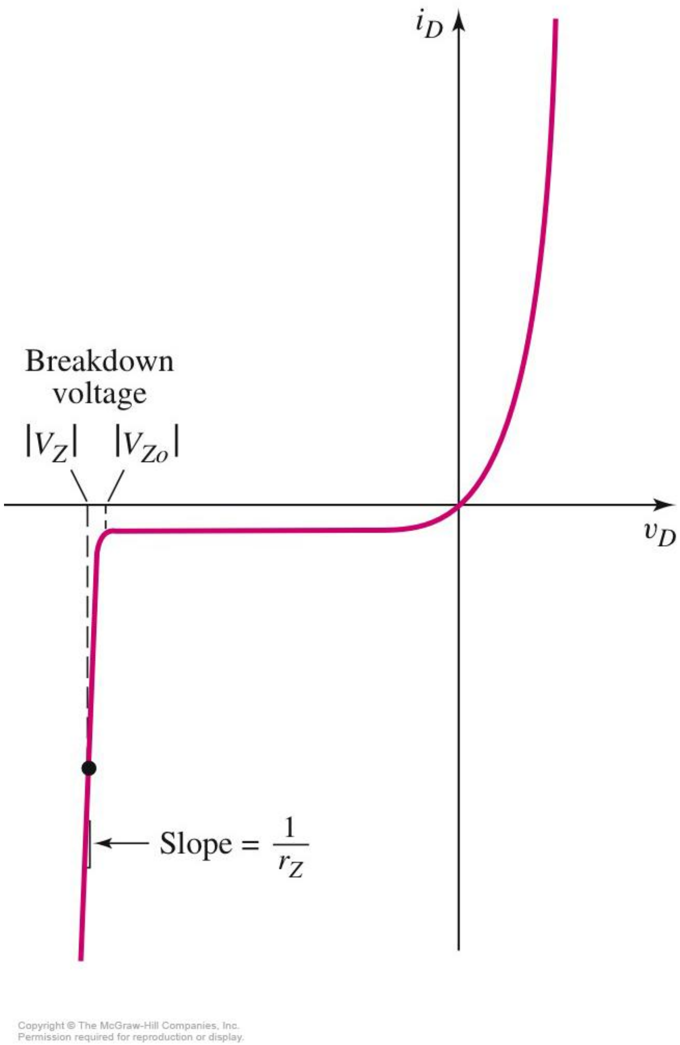
The built-in voltage of the Schottky barrier diode, V_γ(SB), is about ½ as large as the built-in voltage of the p-n junction diode, V_γ(pn),.

The most important difference between the p-n diode and the Schottky diode is the reverse recovery time, when the diode switches from the conducting to the non-conducting state.

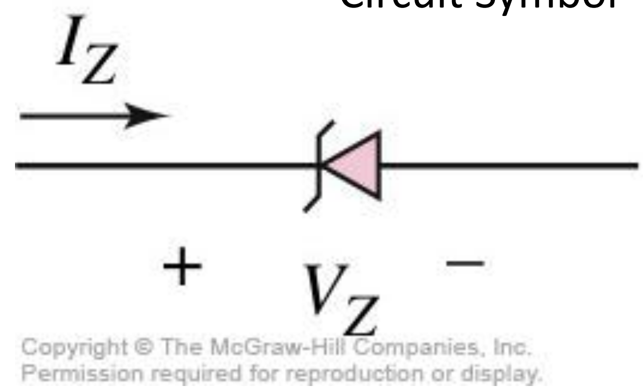


Various Schottky-barrier diodes: Small-signal RF devices (left), medium- and high-power Schottky rectifying diodes (middle and right) -Wiki

Zener Diode
I-V Characteristics



Circuit Symbol



Usually operated in reverse bias region near the breakdown or Zener voltage, V_Z.

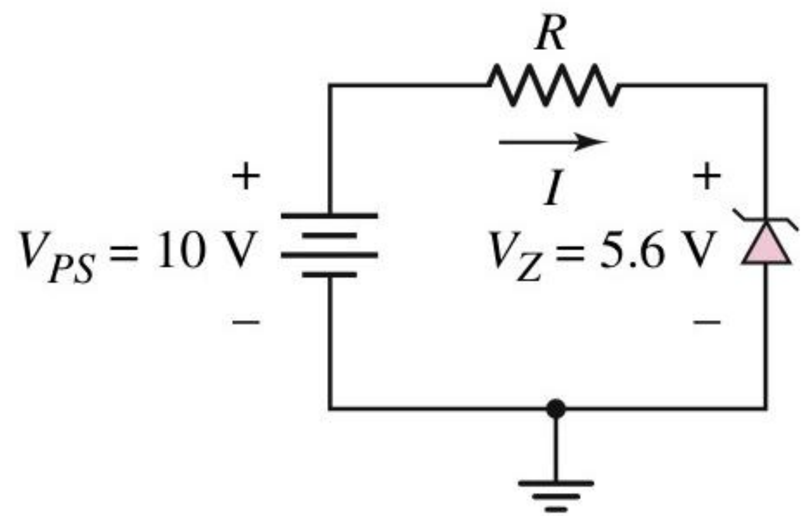
Note the convention for current and polarity of voltage drop.

Example 1

Given $V_Z = 5.6V$

$r_Z = 0\Omega$

Find a value for R such that the current through the diode is limited to 3mA



$$I = \frac{V_{PS} - V_Z}{R}$$

$$R = \frac{V_{PS} - V_Z}{I} = \frac{10V - 5.6V}{3mA} = 1.47k\Omega$$

$$P_Z = I_Z V_Z = 3mA \cdot 5.6V = 1.68mW$$

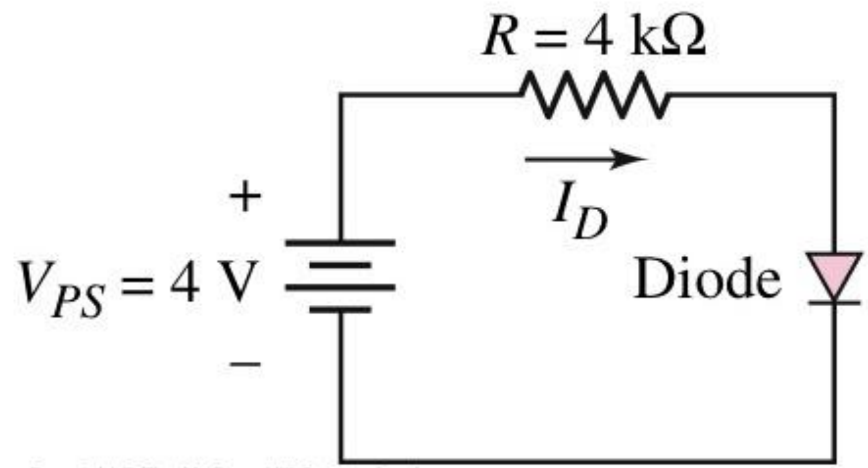
Example 2

Given V_γ (pn) = 0.7V

$V\gamma$ (SB) = 0.3V

r_f = 0Ω for both diodes

Calculate I_D in each diode.



$$I = \frac{V_{PS} - V_\gamma}{R}$$

$$I = \frac{4V - 0.7V}{4k\Omega} = 0.825mA \text{ for the p-n junction diode}$$

$$I = \frac{4V - 0.3V}{4k\Omega} = 0.925mA \text{ for the Schottky diode}$$

Chapter 1 Summary

- First class introduction to Microelectronics
- Overview of Microelectronics, its significance, current state of the art and future prospects
- Intro to semiconductor material properties mainly Si and GaAs, discuss the two types of charged carriers that exist in a semiconductor and the two mechanisms that generate currents in a semiconductor.
- Covered the properties of a pn junction including the ideal current–voltage characteristics of the pn junction diode.
- Examined the DC analysis techniques for diode circuits using various models to describe the nonlinear diode characteristics.
- Develop an equivalent circuit for a diode that is used when a small, time varying signal is applied to a diode circuit.
- Go over the properties and characteristics of a few specialized diodes.

Keywords: carrier, electron, hole, donor, acceptor, diffusion, drift, build-in potential, forward bias, reverse biase, break-down voltage, load line, Q-point, DC&AC analysis