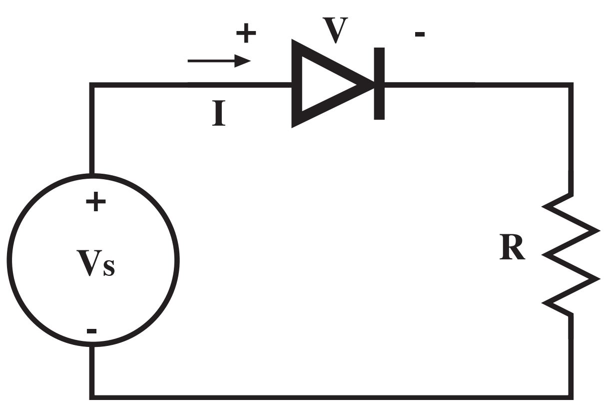
EE 2200 INTRO. TO ELECTRONIC DEVICES

Materials and device structures for applications in analog and digital electronics. Topics include characteristics and basic circuits for diodes, field-effect transistors, bipolar junction transistors, and operational amplifiers. (Prerequisites: Physics 2135, EE 2100, and EE 2101 with a Grade of "C" or better)

Students must enroll in EE 2200 and EE 2201 (Electronic Devices Laboratory) simultaneously.

Objectives:

- To understand basic crystal physics including steady-state resistivity and carrier transport.
- To understand basic characteristics of diodes, FETs, BJTs, and Ideal Op Amps.
- To apply DC analyses to the devices listed above in digital and analog electronics.
- To introduce fabrication techniques and junction structures in semiconductors.



EE 2200 INTRODUCTION TO ELECTRONIC DEVICES INFORMATION

This information shows typical course details. Refer to the instructor syllabus for information pertaining to a specific course section and semester.

Typical Course Grading:

Attendance	Daily
Examinations	3
Quizzes	~4
Homework	~10
Final	1

Typical Course Outline (Times Approximate):

Introduction & Semiconductor Crystals	1 week
Carriers and Doping (resistivity)	1 week
Drift and Diffusion Currents and Junctions	1 week
Diodes and Diode Circuits	1 week
Review, Exam. #1, & Solution	1 week
BJT Devices, Circuits, and Applications	1.5 weeks
FET Devices, Circuits, and Applications	1.5 weeks
Device Fabrication	1 week
Review, Exam. #2, & Solution	1 week
Ideal Op Amps and Circuits	2 weeks
Laser Diodes and Photodiodes	2 weeks
Review, Exam. #3, & Solution	1 week
Final Review	
COMMON FINAL EXAM*	**Scheduled During Finals Week**

Common Final Examination*:

Format: Student work eight of ten problems for a two-hour examination

A sheet of selected equations is provided with the examinations

Content Emphasis:

- Semiconductor Crystal and Junction Physics (2 problems)
- Diode Circuits (1 problem)
- Bipolar Junction Transistors (2 problems)
- Field Effect Transistors (2 problems)
- OpAmp Circuits (2 problems)
- Optoelectronics (1 problem)

*** NOTE:**

You must earn a “C” or better to enroll in EE 3100 Electronics I.

You must earn a “C” or better on the final to earn a "C" in the class.

SELECTED COURSE INFORMATION

EE 2200 Resources http://ece.mst.edu
Course resources are available on the ECE Department Webpage. Under EE 2200 Class Notes this information includes

- EE 2200 Introduction
- ECE Advancement Exam Guidelines and Example Problems
- EE 2200 Final Examination Equation Sheet
- EE 2200 Sample Final Examination/EEAE III
- EE 2200 Worksheets
- EE 2200 Course Lecture Notes

Under Practice Electrical Engineering Advancement Exams, additional final example problems are given.

- Advancement Exam 3 (EE 2200)

Useful Optional Reference Texts These and similar texts may be found in the campus library

- Streetman & Banerjee, *Solid State Electronic Devices*, 6th ed. (PH, 2005)
- Burns & Bond, Principles of Electronic Circuits, 2nd ed. (PWS, 1997).
- Cunningham & Stuller, *Circuit Analysis,* 2nd ed. (JW,1995) especially Chapter 6.
- Alexander & Sadiku, *Fundamentals of Electric Circuits*, 6th ed. (2021), especially Chap. 5 OpAmps and Chap. 7 Section 7.7 OpAmp Circuits

Canvas Public Course

- Circuits Resources: Devices: MST-Circuits Resources-PCI

Tutoring Sessions and Other Resources

- LEAD Learning Assistance (http://lead.mst.edu)
- IEEE/HKN Assistance (EECH 202)

Success in Passing the Final and Passing the Course

Lectures and Public Canvas Public Course Material
Review Notes before Class and Use Canvas Public Course after Class

Spend Time with Homework and Worksheet Problems (with Equation Sheets)
Use Equation Sheets while Working Homework and Example Problems

Ask Questions during Instructor Office Hours

Use the LEAD Sessions and IEEE/HKN Tutoring Sessions

Other: Form a Study Group, Read Optional Texts, etc.

Exam Preparation
Review Homework, Work Example Exam Problems, and Re-work Worksheets

SI - Systéme International d'Unités (International System of Units)
The units system has only one recognized unit for each physical quantity and is fully consistent in which no conversion factors are needed in calculations.

Base Units:*

Quantity	Unit	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	**ampere**	**A**
temperature	kelvin	K
amount	mole	mol
luminous intensity	candela	cd

* Sometimes referred to as the MKS or MKSA system.

Derived Units:

Quantity	Unit	Symbol	Equivalent
plane angle	radian	rad	m/m=1 (arc length to radius)
solid angle	steradian	sr	$m^2/m^2=1$ (area to radius squared)
frequency	**hertz**	**Hz**	**(cycles) s^{-1}**
energy	**joule**	**J**	**kg m^2/s^2**
power	**watt**	**W**	**J/s**
force	newton	N	kg m/s^2
charge	**coulomb**	**C**	**A s**
electric potential	**volt**	**V**	**J/C**
resistance	**ohm**	**Ω**	**V/A**
capacitance	**farad**	**F**	**C/V**
inductance	**henry**	**H**	**Wb/A or V s/A**
magnetic flux	weber	Wb	V s
magnetic flux density	tesla	T	Wb/m^2
luminous flux	lumen	lm	cd sr
illuminance	lux	lx	lm/m^2

Non-SI Units:

Quantity	Unit	Symbol	Equivalent
length	angstrom	Å	10^{-10} m
energy	**electron-volt**	**eV**	~1.602 18x10^{-19} J
plane angle	degree	°	π/180 rad

Prefixes

Factor	Prefix	Symbol
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f

Preferred Notation:

Length, Area, and Volume - centimeter (cm), centimeters squared (cm^2), and centimeters cubed (cm^3)
Mass - grams (g)
Electric Field E - volts per centimeter (V/cm)
Magnetic Field H - amperes per centimeter (A/cm)
Current Density - amperes per centimeter squared (A/cm^2)
Electron Energy - electron-volts (eV)
Photon Energy - electron-volts (eV)
Irradiance I - watts per centimeter squared (W/cm^2)
Wavelength λ - micron (μm) or nanometer (nm)

Prefixes - Use Factors of Three (cm is the exception)
Use SI units (note capitalization) in standard forms (e.g. W not J/s and Ω not V/A)
Lowercase Variables – time-dependent quantities
Uppercase Variables – time-independent quantities

Greek Alphabet:

Letter	Upper Case	Lower Case
alpha	Α	α
beta	Β	β
gamma	Γ	γ
delta	Δ	δ
epsilon	Ε	ε
zeta	Ζ	ζ
eta	Η	η
theta	Θ	θ
iota	Ι	ι
kappa	Κ	κ
lambda	Λ	λ
mu	Μ	μ
nu	Ν	ν
xi	Ξ	ξ
omicron	Ο	ο
pi	Π	π
rho	Ρ	ρ
sigma	Σ	σ
tau	Τ	τ
upsilon	Υ	υ
phi	Φ	ϕ
chi	Χ	χ
psi	Ψ	ψ
omega	Ω	ω

ELECTRICAL CLASSIFICATION OF SOLIDS

Semiconductor - a material having an electrical conductivity which is a strong function of *temperature*, *purity*, and *optical excitation*, for example near absolute zero high-purity silicon is an insulator and at room temperature σ (high-purity silicon) ~ 4×10^{-6} $(\Omega\text{-cm})^{-1}$.

Insulator - a material having a low electrical conductivity, for example at room temperature σ(porcelain) ~ 10^{-12} to 10^{-14} $(\Omega\text{-cm})^{-1}$

Conductor - a material having a high electrical conductivity, for example at room temperature σ(copper) ~ 6×10^{5} $(\Omega\text{-cm})^{-1}$

STRUCTURE OF SOLIDS

Crystalline Solid - a material having a three-dimensional periodic array of atoms.

Polycrystalline Solid - a material composed of small regions of crystalline regions that are misoriented relative to one another.

Amorphous Solid - a material with no periodic structure.

CRYSTAL STRUCTURE OF IMPORTANT SEMICONDUCTORS

Diamond Lattice - 2 interpenetrating face-centered cubic (fcc) sublattices composed of the same material; each atom has four nearest neighbors.

Zincblende Lattice - 2 interpenetrating fcc sublattices composed of different material; each atom has four nearest neighbors of the other type.

SEMICONDUCTOR PHYSICS

Electron - an elementary negatively-charged particle. (cf. photon)

Hole - the absence of an electron in a crystal bond which is mathematically equivalent to a mobile positively-charged particle.

Elemental Semiconductor - a semiconductor composed of a single species of atom. They are found in column IV (periodic table) and include silicon (Si) and germanium (Ge).

Compound Semiconductor - a semiconductor composed of two or more species of atom. They are formed from some combinations of elements in columns II, III, IV, V, and VI.
Common Binary III-V Semiconductors: GaAs, AlP, InSb, and InP
Common Binary II-VI Semiconductors: ZnSe, CdTe, and CdSe
Common Ternary Semiconductor: GaAsP and AlGaAs
Common Quaternary Semiconductors: GaInAsP and AlGaAsSb

Intrinsic Semiconductor - a semiconductor containing no impurity atoms or an insignificant amount of impurity atoms such that its properties are native to the material.

Extrinsic Semiconductor - a semiconductor in which impurities control electrical properties.

Dopants - specific impurity atoms which are incorporated in controlled amounts for the express purpose of increasing the concentrations of electrons or holes.

Donors - impurity atoms which increase the concentration of mobile electrons.

Acceptors - impurity atoms which increase the concentration of holes.

Majority Carrier - the most abundant charge carrier in a semiconductor.

Minority Carrier - the least abundant charge carrier in a semiconductor.

n-type Material - a semiconductor having electrons as the majority carriers.

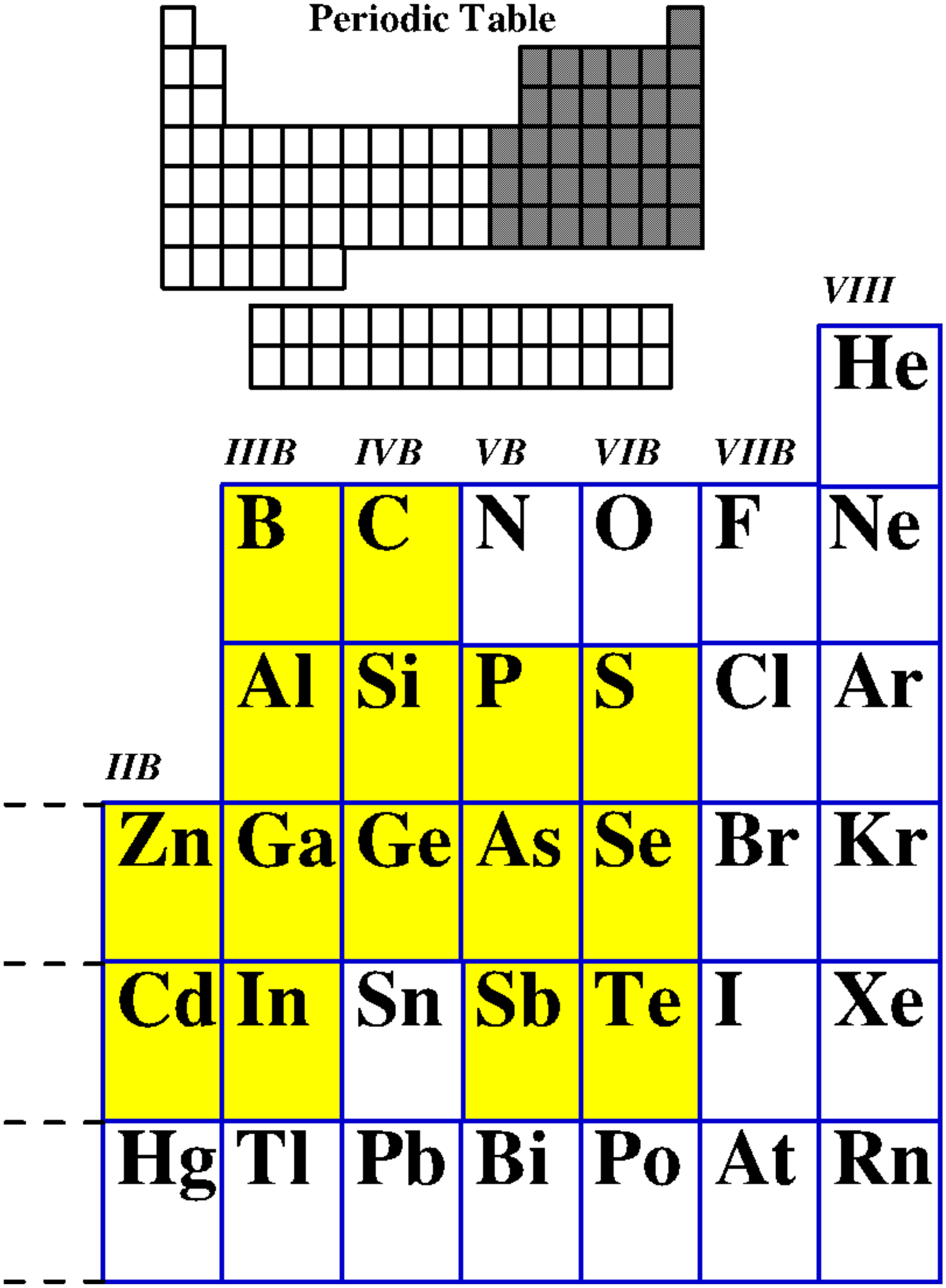
p-type Material - a semiconductor having holes as the majority carriers.

SEMICONDUCTOR DEVICES

Electronics - science and technology concerned with the behavior of electrons. (cf. photonics)
Homo- (junction or structure) – an interface, e.g. pn, in the same semiconductor.
Hetero- (junction or structure) – an interface between different bandgap semiconductors.
Step-junction – an interface between n-type and p-type material with an abrupt doping change.
Diode - the two-terminal device with p-type and n-type regions in which the electrical behavior differs for forward and reverse bias.
Transistor – a three-terminal device for which the voltage or current at one terminal controls the electrical behavior of the other terminals.
Field Effect Transistor or FET - a three-terminal device for which the voltage at one terminal controls the electrical behavior of the other terminals.
Bipolar Junction Transistor or BJT - a three-terminal device for which the current at one terminal controls the electrical behavior of the other terminals.
Operational Amplifier or Op Amp – a complex device that may be modeled as a voltage-controlled voltage source with high gain, high input impedance, and low output impedance.
Equilibrium - carrier concentrations are unchanging and are determined only by host material, impurities, and temperature.
Steady-state - carrier concentrations are unchanging without transients from external conditions.
Ohmic Contact - a perfect source or sink of both holes and electrons with no tendency to inject or collect either carrier type.

PHOTONIC RELATIONSHIPS

Electromagnetic (EM) Spectrum - radiation of all frequencies or wavelengths including electrical power transmission, radio frequencies, optical frequencies, and high-energy rays. Wavelength λ (in vacuum) or frequency f are related by λ f = c = speed of light in vacuum.
Radiation - energy emitted or propagated as waves and energy quanta.
Photon - a quantum of electromagnetic energy with no mass, no charge, and energy hc/λ.
Light - electromagnetic radiation in the ultraviolet, visible, and infrared bands or optical range
Infrared Spectrum (IR) - EM band with wavelengths between about 700 nm and 10^5 nm.
Visible Spectrum - EM band with wavelengths between about 450 nm and 700 nm; radiation detectable by the human eye.
Ultraviolet Spectrum (UV) - EM band with wavelengths between about 1 nm and 450 nm.
X-rays - electromagnetic radiation with wavelengths between about 10 nm and 0.01 nm; usually described as high-energy photons.
Photonics - science and technology concerned with the behavior of photons.
Optoelectronics - the technology in which optical radiation is emitted, modified, or converted (as in electrical-to-optical or optical-to-electrical).
Photodiode (PD) – an optoelectronic device that is based on a semiconductor junction which absorbs light and converts the light input to a current.
Laser – (light amplification by stimulated emission radiation) a device that emits optical radiation which is coherent, highly directional, and nearly monochromatic.
Laser Diode (LD) – an optoelectronic device that is based on a semiconductor junction which emits optical laser radiation at a photon energy close to bandgap of the junction.
Light Emitting Diode (LED) – an optoelectronic device which emits non-coherent optical radiation at a photon energy close to bandgap of the junction.
Radiometry – the measurement of radiant EM energy at specific wavelength ranges.


Periodic Table
VIII
He
IIIB IVB VB VIB VIIB
B C N O F Ne
Al Si P S Cl Ar
IIB
Zn Ga Ge As Se Br Kr
Cd In Sn Sb Te I Xe
Hg Tl Pb Bi Po At Rn

IMPORTANT CONSTANTS AND UNITS

Electron Charge	$q = 1.602 \times 10^{-19}$ C
Electron Mass	$m = 9.109 \times 10^{-31}$ kg
Permeability (Vacuum)	$\mu_O = 4\pi \times 10^{-9}$ H/cm
Permittivity (Vacuum)	$\varepsilon_O = 8.854 \times 10^{-14}$ F/cm
Speed of Light (Vacuum)	$c = 2.998 \times 10^{10}$ cm/s
Planck's Constant	$h = 4.136 \times 10^{-15}$ eV-sec $= 6.626 \times 10^{-34}$ J-sec
Boltzmann's Constant	$k = 1.38 \times 10^{-23}$ J/K $= 8.62 \times 10^{-5}$ eV/K
Electron-Volt	1 eV $= 1.602 \times 10^{-19}$ J
Avogadro's Number	$N_A = 6.02 \times 10^{23}$ molecules per mole
RT* Value of kT	$kT = 0.0259$ eV

*RT = Room Temperature (300 K)

PROPERTIES OF SELECTED SEMICONDUCTORS

Diamond Carbon (C)
Bandgap at RT: $E_G = 5.5$ eV
Lattice Constant: $a = 0.3567$ nm

Silicon (Si)
Bandgap at RT: $E_G = 1.12$ eV
Lattice Constant: $a = 0.5431$ nm
Intrinsic Mobility for Electrons: $\mu_N = 1450$ cm^2 /V s
Intrinsic Mobility for Holes: $\mu_P = 500$ cm^2 /V s

Germanium (Ge)
Bandgap at RT: $E_G = 0.67$ eV
Lattice Constant: $a = 0.5658$ nm
Intrinsic Mobility for Electrons: $\mu_N = 3900$ cm^2 /V s
Intrinsic Mobility for Holes: $\mu_P = 1800$ cm^2 /V s

Gallium Arsenic (GaAs)
Bandgap at RT: $E_G = 1.42$ eV
Lattice Constant: $a = 0.5653$ nm
Intrinsic Mobility for Electrons: $\mu_N = 9200$ cm^2 /V s
Intrinsic Mobility for Holes: $\mu_P = 400$ cm^2 /V s

*Reference: *Semiconductor – Basic Data*, 2nd Edition, Otfried Madelung (editor), (Springer-Verlag, Berlin, Germany, 1996).

COMMON VALUES FOR INTRINSIC CARRIER CONCENTRATIONS

Silicon (Si)	Intrinsic concentration at RT: $n_I = 1.5 \times 10^{10}$ cm^{-3}
Germanium (Ge)	Intrinsic concentration at RT: $n_I = 2.3 \times 10^{13}$ cm^{-3}
Gallium Arsenic (GaAs)	Intrinsic concentration at RT: $n_I = 2.1 \times 10^{6}$ cm^{-3}