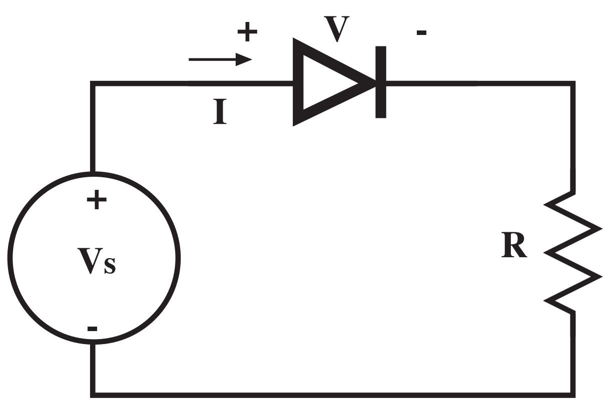
EE 121 INTRO. TO ELECTRONIC DEVICES

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 24, EE 151, and EE 152 with a Grade of "C" or better)

Students should enroll in EE 121 and EE 122 (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 121 INTRODUCTION TO ELECTRONIC DEVICES INFORMATION

Course Grading:

Attendance	Daily
Examinations	3
Quizzes	8
Homework	10
Final	1

Course Outline:

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
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 253 Electronics I.
You must earn a "C" or better on the final to earn a "C" in the class.

Course Policies:

GRADES

Letter grades will be based on logical break points in the class distribution. **However, you must earn a “C” or better on the final to earn a "C" or better in the class!** If a “C” or better is earned on the final, grades will be no lower than A for 90% or greater, B for 80% to 90%, C for 70% to 80%, and F for less than 70%. For borderline cases, I reserve the right to consider such things as consistency of scores, class participation, perceived effort, attendance, etc.

STUDENT CONDUCT

Students are responsible for all material announced/presented in class and sent by E-mail. E-mail will be used to distribute class announcements, corrections to assignments, etc. Regular attendance to class is expected. Attendance will be taken at the BEGINNING of every class period. At the instructor's discretion, absence or tardiness **may** be excused if prior arrangements are made. The only exceptions are documented emergencies or sudden illnesses. A student may be dropped for excessive absences or unsatisfactory work (see *Student Academic Regulations*). Students should be aware of the Academic Alert System and they are responsible for communications through this system.

If you have a documented disability and anticipate needing accommodations in this course, you should make arrangements early in the semester. Students must request that the Disability Services Staff send a letter verifying the disability and specifying the accommodation needed before such accommodation can be provided.

Incidents of dishonesty, cheating, copying, plagiarism, sabotage, etc. will be subject to substantial penalties. Expectations of students are specified in *Student Academic Regulations*. Seek the instructor’s guidance on what is acceptable collaboration, conduct, etc. You are responsible for writing your own assignments and for preventing others from copying your work. The use of cell phones or other communication during exams will be considered potential cheating and will be subject to penalties.

Any form of academic dishonesty and other misconduct will result in full or partial loss of assignment credit and other penalties (including failure of the course) at the discretion of the instructor and the department! The department can also recommend expulsion from the university.

EXAMINATIONS AND QUIZZES

The exams will closed book and will cover all material assigned to date (e.g. exam #2 may include material also covered in exam #1). The final will be comprehensive. All significant steps to answers must be shown. All answers must be shown in appropriate units. A review sheet will be distributed before each exam. No notes or books will be allowed in the exams. All or specific types of calculators may be excluded at the instructor’s discretion.

Make-up exams will be at the instructor’s discretion. They must be arranged PRIOR to the scheduled test date, except in the event of emergencies and sudden illness (which must be documented by the student). If no prior arrangements are made, the missed exams will receive ZERO CREDIT. The questions on make-up exams may be different than those on regular exams.

The final exam is a common examination which includes all sections of EE 121. It will be given at the time scheduled by the registrar. Make vacation and employment plans accordingly.

Ten-minute quizzes may occasionally be given at the beginning of the class period. These will be announced during the immediately preceding class or by E-mail. If prior arrangements are not made and approved, missed quizzes will receive ZERO CREDIT.

HOMEWORK

Homework will be regularly assigned. It must be turned in at the beginning (first five minutes) of the class period for which it is due. LATE HOMEWORK WILL NOT BE ACCEPTED AND WILL RECEIVE ZERO CREDIT. If you cannot attend class, the homework must be turned in early for credit. Solutions to the homework will be available on file in the library. You may work together on the homework, but the solutions must be substantially your own. Incidents of copying will result in zero credit on the entire assignment for everyone involved and may result in other disciplinary action at my discretion.

The homework sheets must be 8(1/2) x 11 inch pages and must be legible, neat, and stapled together (e.g. pages torn from a spiral notebook and/or pages with extraneous material on the back will not be accepted). The first page must show your name, course number, and assignment number at the top right-hand corner (an example is shown below). All solution steps must be shown in a logical sequence. Answers must be shown in appropriate units. Failure to follow these instructions will result in zero or reduced credit. The lowest NONZERO regular homework score will be dropped (any scores for quizzes and special homework assignments will not be dropped).

Joe Miner
EE 121X
Assignment X

Academic Alert System http://academicalert.mst.edu
The online Academic Alert System provides one means of communication among students, instructors, and advisors.

Academic Dishonesty http://registrar.mst.edu/academicregs/index.html
The student Academic Regulations describes the student standard of conduct relative to the System's Collected Rules and Regulations and offers general descriptions of academic dishonesty including cheating, plagiarism, or sabotage.

Campus Egress Maps http://registrar.mst.edu/links/egress.html
The emergency exits for the campus classrooms are posted at the listed link.

Disability Support Services http://dss.mst.edu
Disability Support Services is located in 204 Norwood Hall and has a telephone number 341-4211. If you have a documented disability and anticipate needing accommodations in this course, you should meet with the instructor immediately. You must contact the Disability Services staff for a letter verifying the disability and specifying the accommodation that is needed. The instructor must have this letter to provide the accommodation.

LEAD Learning Assistance http://lead.mst.edu
For information on learning assistance and tutoring for selected courses please contact the LEAD office at 341-4608 or E-mail lead@mst.edu.

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)** $\mathbf{s^{-1}}$
energy	**joule**	**J**	**kg** $\mathbf{m^2/s^2}$
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 $\lambda f = c$ = 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.

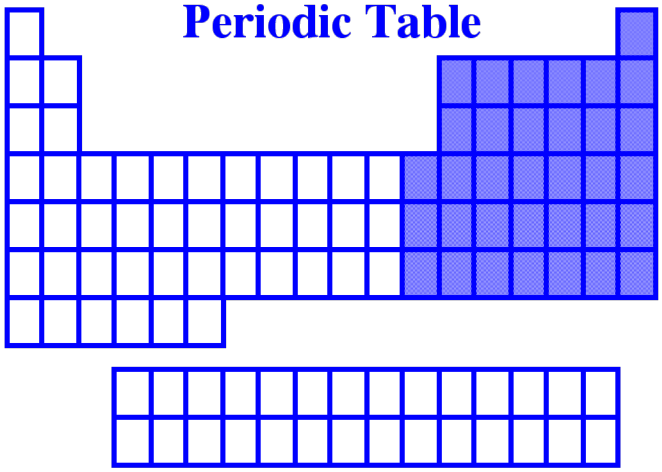
Laser – (light amplification by stimulated emission radiation) a device that emits optical radiation which is coherent, highly directional, and nearly monochromatic.

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



IIB	IIIB	IVB	VB	VIB	VIIB	VIII
						He
	B	C	N	O	F	Ne
	Al	Si	P	S	Cl	Ar
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}