VE 320 Summer 2019

Introduction to Semiconductor Devices

Instructor: Rui Yang （杨睿）

Office: JI Building 434

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Lecture 1

Information session &
Introduction to solids and crystal structures
(Chapter 1)

About the instructor

- 2011.08 – 2016.05. Ph.D., Electrical Engineering, Case Western Reserve University
  - TA of three courses
- 2016.07 – 2018.07. Postdoc Fellow, Electrical Engineering, Stanford University
- 2018.08 – present. Assistant Professor, UM-SJTU Joint Institute, Shanghai Jiao Tong University, Shanghai, China
  - Instructor of VE215

Course schedule

- Lectures: Monday 10:00 – 11:40 am
  Wednesday 10:00 – 11:40 am
  Friday 10:00 – 11:40 am (even weeks)
- Recitation: TBD
- Location: Dong Shang Yuan (D) Room 111
- My office hours: Mo & We 1:30 – 2:30 pm, Rm. 434, UM-SJTU JI Building
- Prerequisites: Ve215, Vp240(or Vp260)
  - If you do not meet this requirement, please see the instructor immediately after class
- TA:
  - Yijin Rui（芮意进）, iregion@sjtu.edu.cn
  - Sheng Shen（申晟）, shensheng97@sjtu.edu.cn

Instructor's contact

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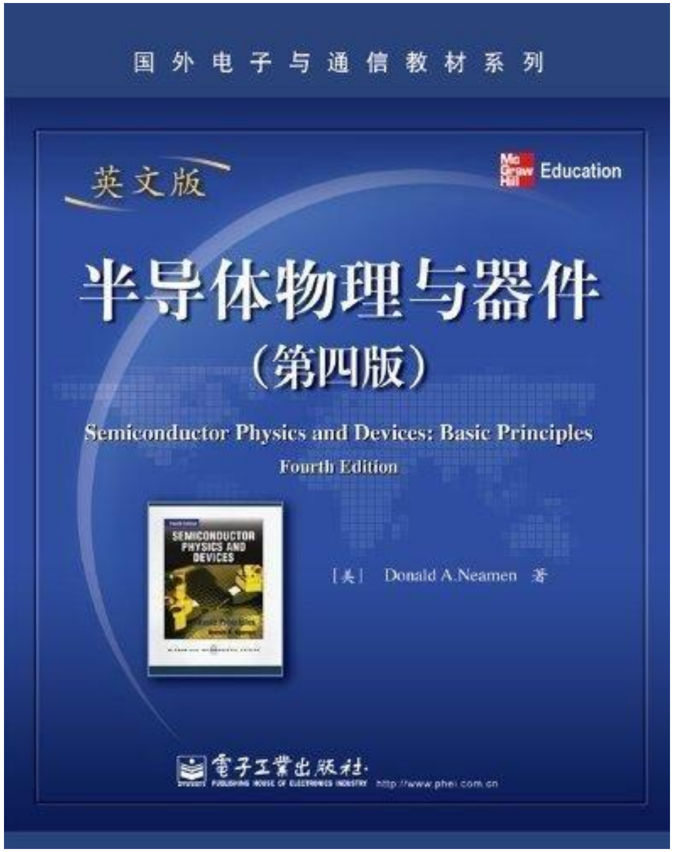
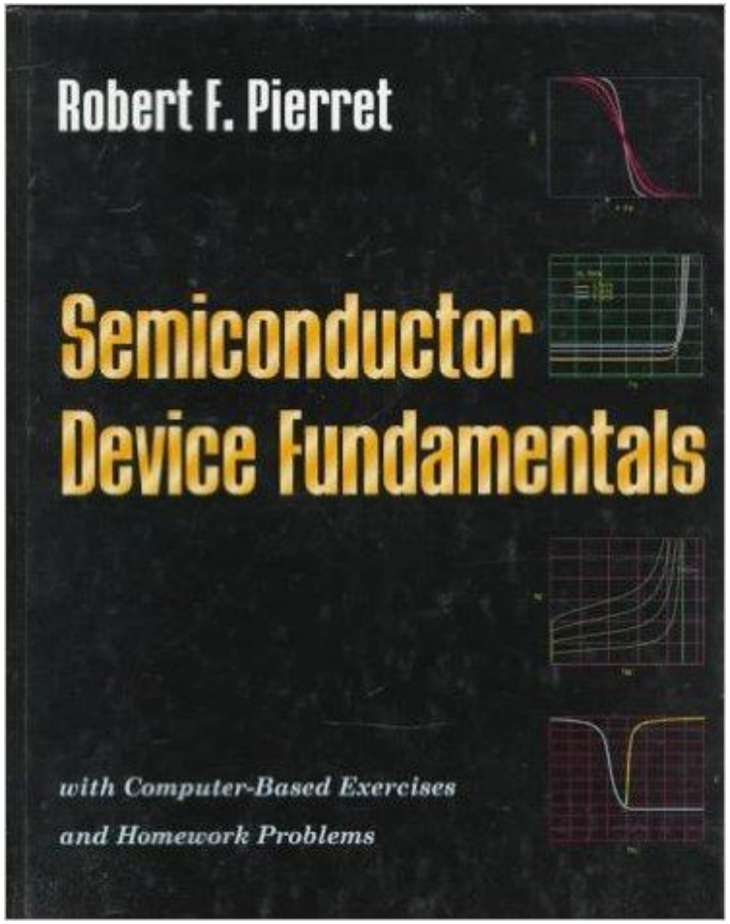
Textbook 1

Semiconductor Physics and Devices: Basic Principles 4th ed.
Donald A. Neamen
Publishing house of electronic industry



Textbook 2

Semiconductor Device Fundamentals, 2nd Ed.
Robert F. Pierret, (available JI library)



Grading policy

- Ve320 has 10 problem sets (homework assignments), and 3 exams
- Random in-class quizzes: 5%
- Problem sets: 5%
- Exam 1(Midterm Exam 1): 30%
- Exam 2(Midterm Exam 2): 30%
- Exam 3(Final Exam): 30%
- Curve to be centered at B or B+

The JI Honor Code

- Personal integrity as students and professionals.
- Respect other people and their work.
- Respect yourself and your own efforts.
- Mutual trust.
- Applicable to all your academic activities here, including homework, quizzes, lab reports, projects and exams.
- Violations will be reported to the Honor Council.
  - Copy other student's homework, quizzes, lab reports, exams.
  - Illegal copy of online resource and academic literatures.
  - Helping others on the abovementioned activities.
  - Fake ID for exams.

Class rules

- Please do not come in late and do not get up to leave until the class is dismissed.
- You are responsible for all material covered in class, whether or not it is in the book.
- Read the book after the class.
- Problem sets (homework assignments) may be discussed with partners, but the work you submit must be your own.
- Homework will be assigned online at Canvas as scheduled. They are usually due one week later or specified otherwise. One day automatic grace period. Second day late penalty -25%, later no credit.

Exam rules

- There will be two midterm exams and one final exam.
- Students should complete the exam independently. No talk and collaboration are allowed.
- Closed book, cheat sheet may be allowed.
- No electronic devices except basic calculators will be allowed to use.
- Random quizzes are open book, but no cheating
- Any suspicious violation of the honor code will be reported to the honor council.

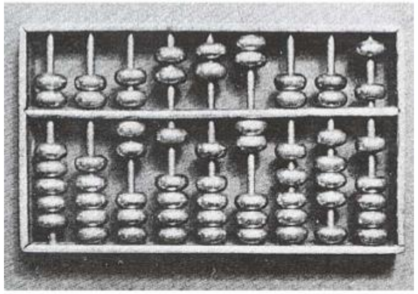
Tentative schedule: (subject to change)

Week	Date	Lecture Topics	Homework
1	May 13	Inroduction to solids, crystal structures	
	May 15	Introduction to quantum mechanics	HW1
2	May 20	Introduction to quantum mechanics	
	May 22	Energy band	HW2
	May 24	Energy band	
3	May 27	DOS and Fermi distribution	
	May 29	DOS and Fermi distribution	HW3
4	Jun. 3	Carrier and transport	
	Jun. 5	Carrier and transport	HW4
	Jun. 7	No Lecture, National Holiday	
5	Jun. 10	Carrier and transport	
	Jun. 12	No Lecture, Midterm Exam 1	HW5
6	Jun. 17	Carrier and transport	
	Jun. 19	PN junction	HW6
	Jun. 21	PN junction	
7	Jun. 24	PN junction	
	Jun. 26	PN junction	HW7
8	Jul. 1	PN junction	
	Jul. 3	BJT	
	Jul. 5	Schottky diode	HW8
9	Jul. 8	Lecture will be rescheduled due to time conflict	
	Jul. 10	Lecture will be rescheduled due to time conflict	
10	Jul. 15	No Lecture, Midterm Exam 2	
	Jul. 17	MOS Capacitor	HW9
	Jul. 19	MOS Capacitor	
11	Jul. 22	MOS Capacitor	
	Jul. 24	MOSFET	HW10
12	Jul. 29	MOSFET	
	Jul. 31	MOSFET	
	Aug. 2	MOSFET	
13	Aug. 9	No Lecture, Final Exam	

Semiconductor Devices

- The abacus, ancient digital memory

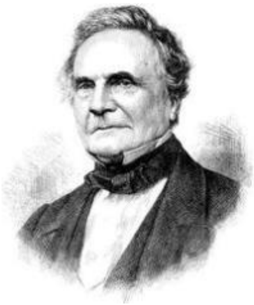
Roman Abacus (ca. 200BC)



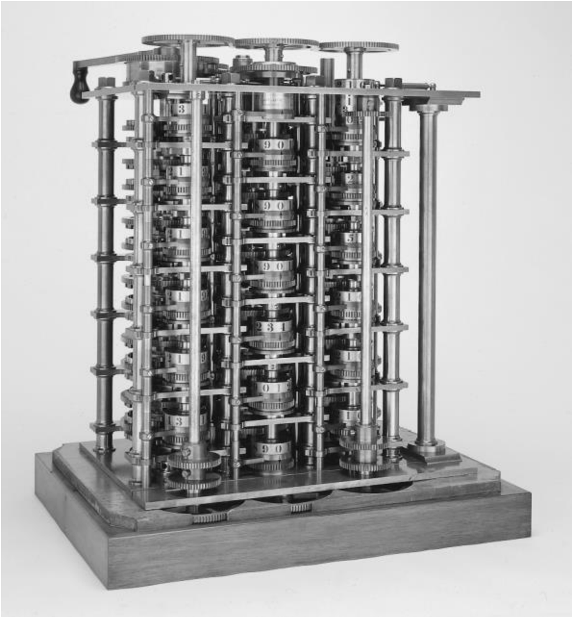
Chinese Abacus (ca. 190AD)

  – Information represented in digital form
  – Each rod is a decimal digit (units, tens, etc.)
  – Can store information, and do calculation

- An early mechanical computer
  – The Babbage difference engine, 1832
  – 25,000 parts



Charles Babbage (Wikipedia)



- Ohm's law: V = I x R
  - Georg Ohm, 1827

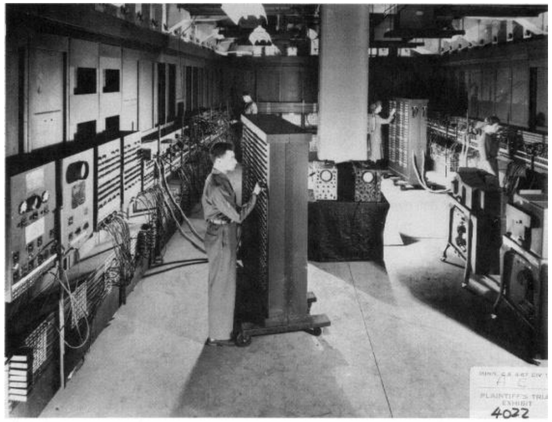
- Semiconductors are <u>not</u> metals
  - Semiconductor resistance <u>decreases</u> with temperature
  - Michael Faraday, 1834

- Discovery of the electron
  - J.J. Thomson, measured only charge/mass ratio, 1897
  - "To the electron, may it never be of any use to anybody." – J.J. Thomson's favorite toast.

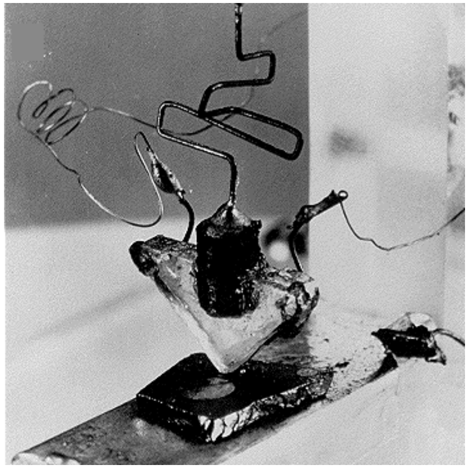
- Measuring the electron charge: 1.6×10^{-19} C
  - Robert Millikan, oil drops, 1909

- ENIAC: The first electronic computer (1946)
  - 30 tons, including ~20,000 vacuum tubes, relays
  - Punch card inputs, ~5 kHz speed
  - It failed ~every five days

Note: ILLIAC @ UIUC
5 tons, 2800 vacuum tubes
64k memory (1952)

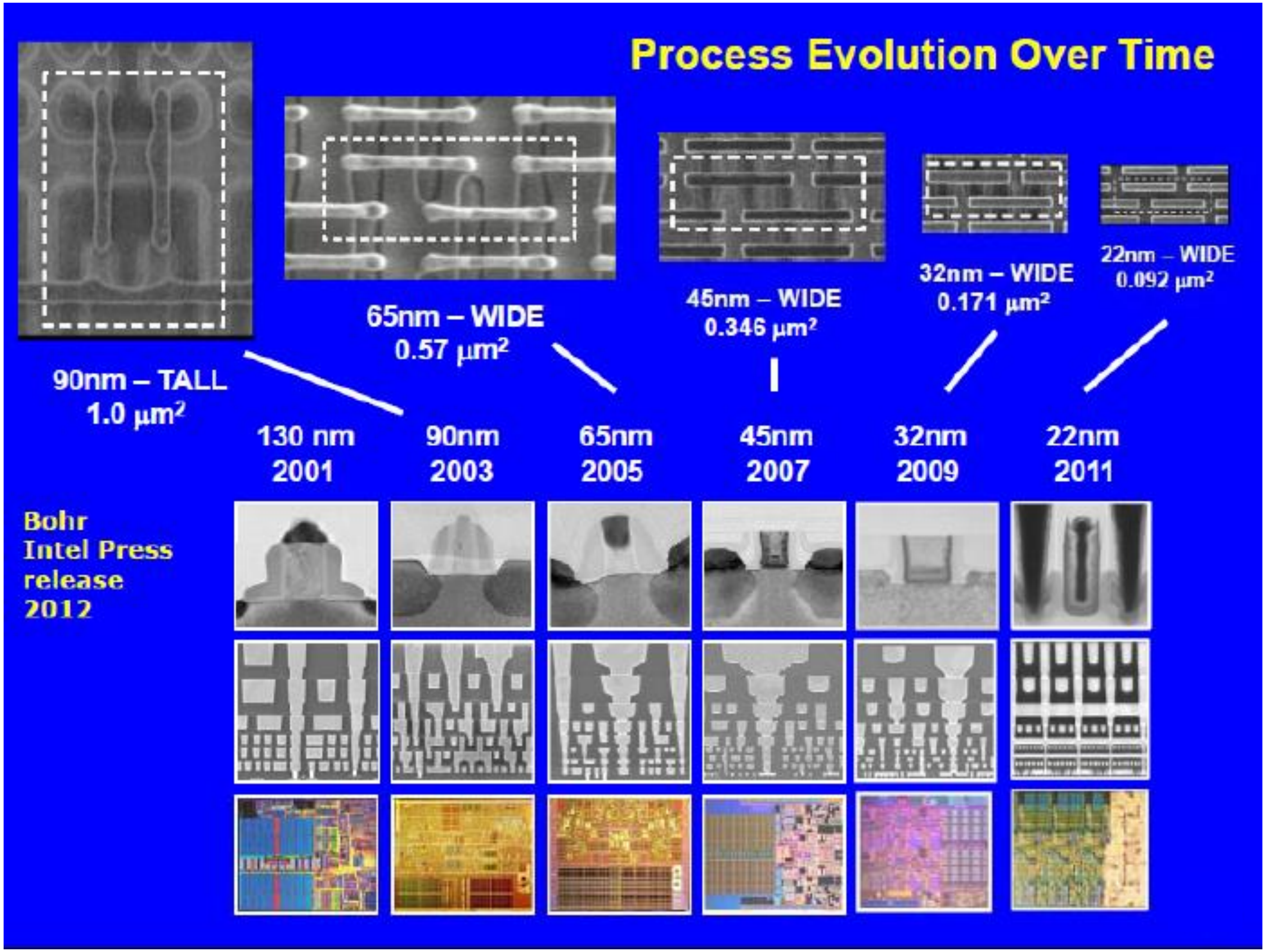


- Modern age begins in 1947:
  - The first semiconductor transistor
  - AT&T Bell Labs, Dec 1947
  - J. Bardeen, W. Brattain, W. Shockley
  - Germanium base, gold foil contacts



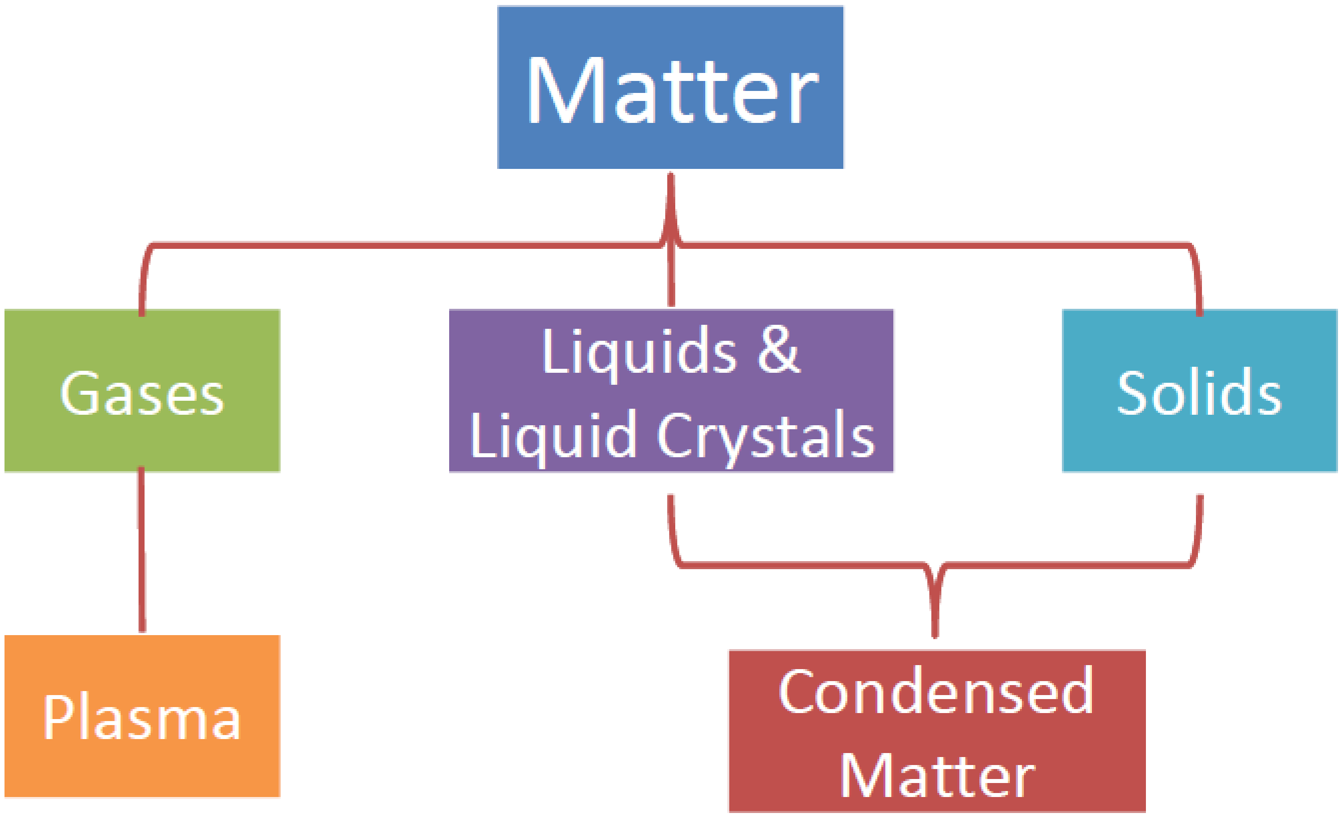
Note: ILLIAC II @ UIUC
Built with discrete transistors (1962)

Semiconductor processing



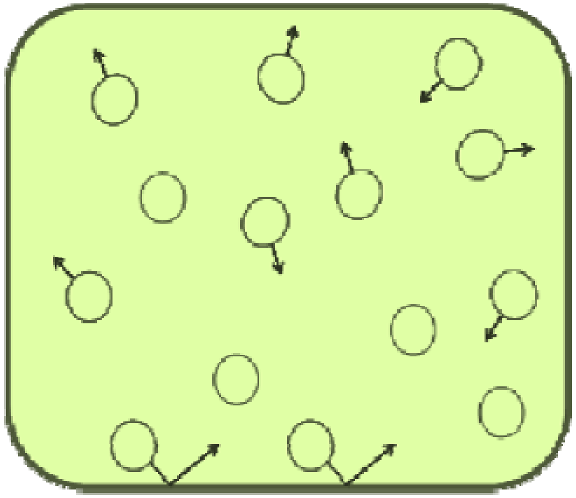
Introduction to solids

States, phases of matter



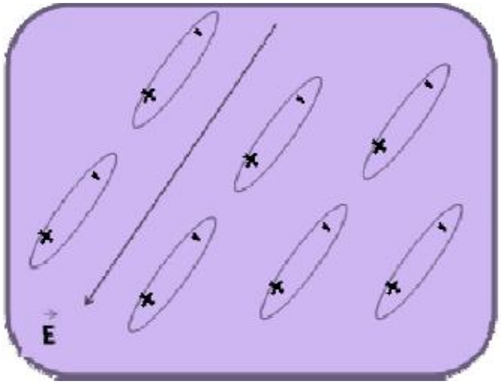
Gases

- ***Gases*** have atoms or molecules that do not bond to one another in a range of pressure, temperature & volume.
- These molecules haven't any particular order & move freely within a container.



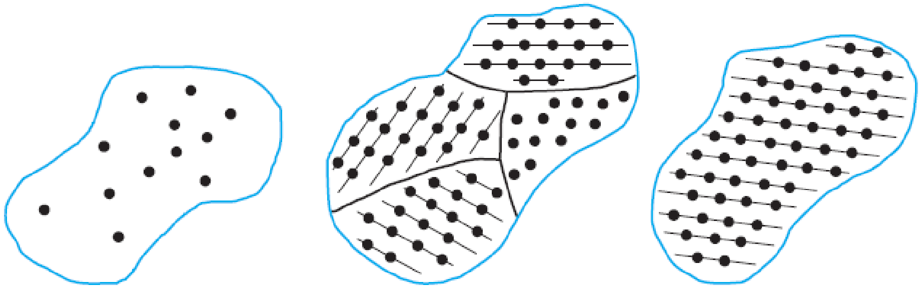
Liquids & liquid crystals

- Similar to gases, ***Liquids*** have no atomic/molecular order & they assume the shape of their containers.
- Applying low levels of thermal energy can easily break the existing weak bonds.
- ***Liquid Crystals*** have mobile molecules, but a type of long range order can exist; the molecules have a permanent dipole. Applying an electric field rotates the dipole & establishes order within the collection of molecules.



Solids

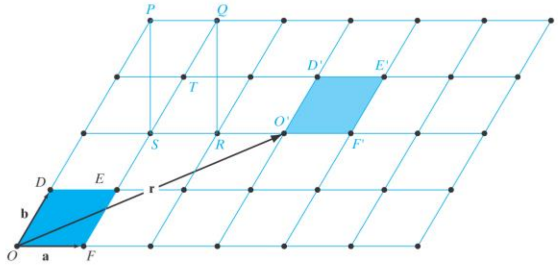
- ***Solids*** consist of atoms or molecules *undergoing thermal motion* about their equilibrium positions, which are at *fixed points* in space.
- *Solids* can be amorphous, polycrystalline, or single crystal.



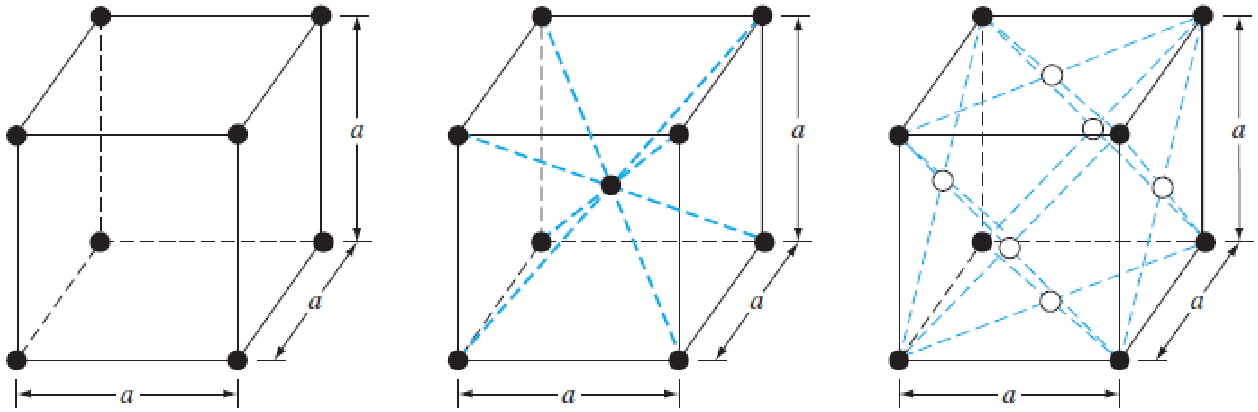
amorphous   polycrystalline   single crystal

- *Solids* (at a given temperature, pressure, volume) have stronger interatomic bonds than liquids.
- So, solids require more energy to break the interatomic bonds than liquids.

- The periodic lattice
  - Unit cell: can reproduce the crystal
  - Primitive cell: the smallest unit cell



- Stuffing atoms into unit cells:

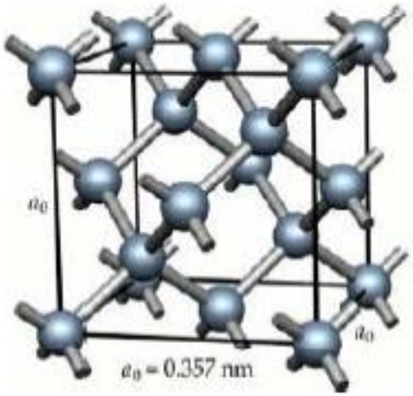


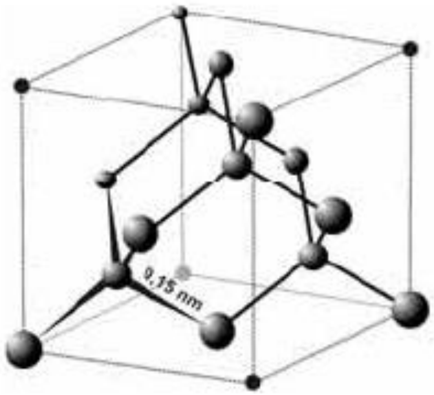
Simple cubic

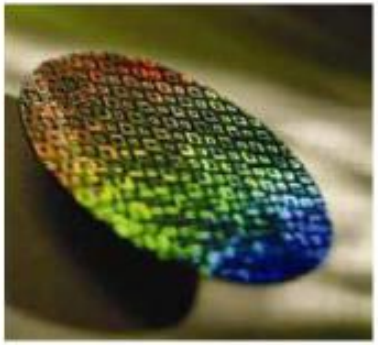
Body-centered cubic

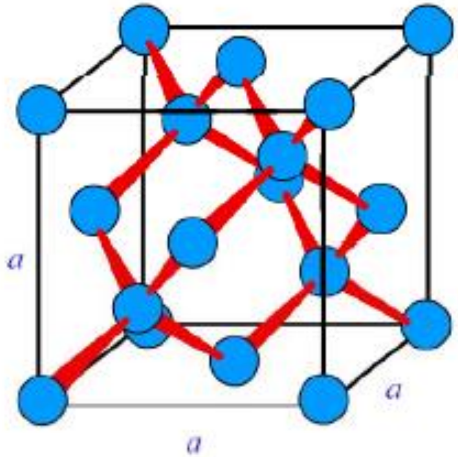
Face-centered cubic

Diamond structure – a special cubic







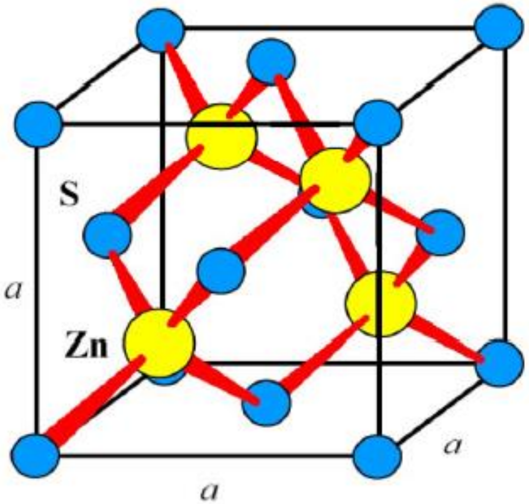


The Silicon lattice:

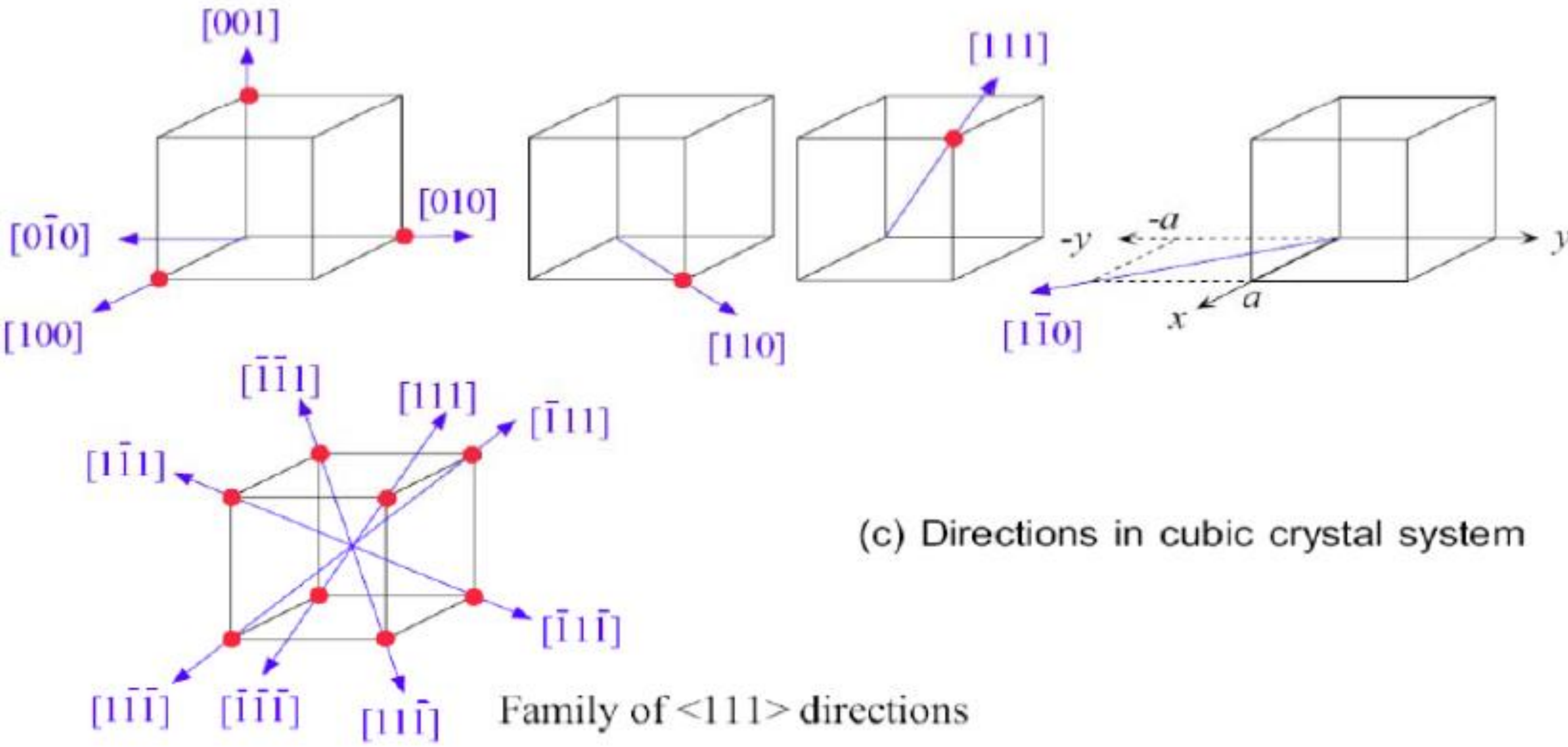
- "Diamond lattice"
- Si atom: 14 electrons occupying lowest 3 energy levels:
  - 1s, 2s, 2p orbitals filled by 10 electrons
  - 3s, 3p orbitals filled by 4 electrons
- Each Si atom has four neighbors
- Any atom within the diamond structure will have four nearest neighboring atoms
- The diamond structure refers to the particular lattice in which all atoms are of the same species, such as silicon or germanium
- How many atoms per unit cell?

Zinc blende lattice

- The Zinc blende is diamond cystal structure, w/ switching atoms
- Two intercalated fcc lattices
- Many important compound crystal
- AlN, AlAs, GaAs, GaN, GaP, GaSb, InAs, InP, InSb, ZnS, ZnTe.

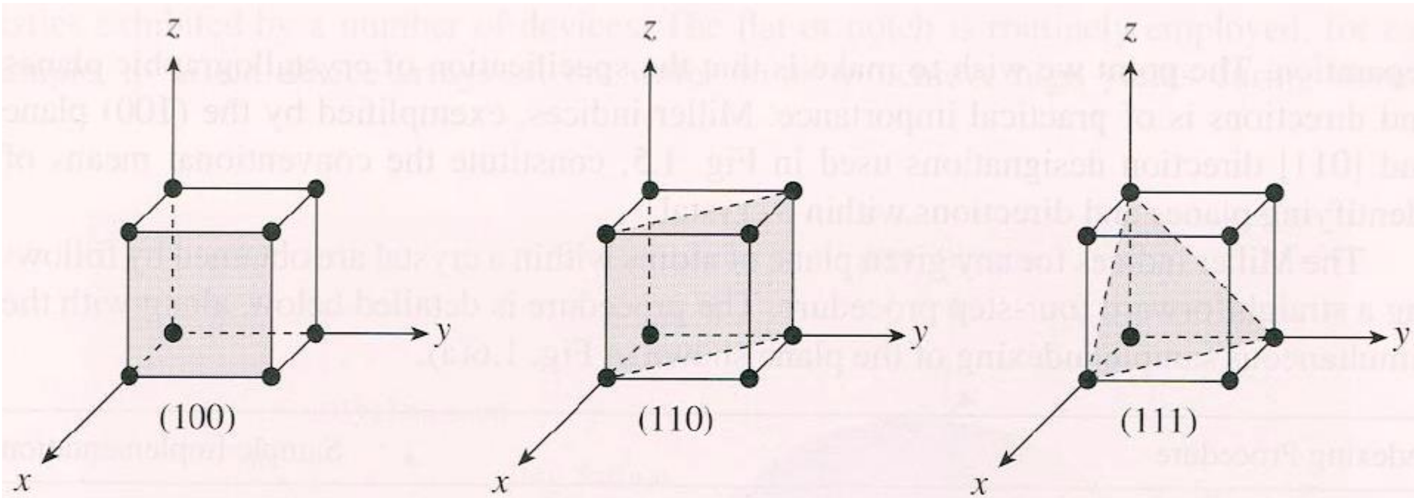


- Crystallographic notation



(c) Directions in cubic crystal system

■ Crystallographic planes

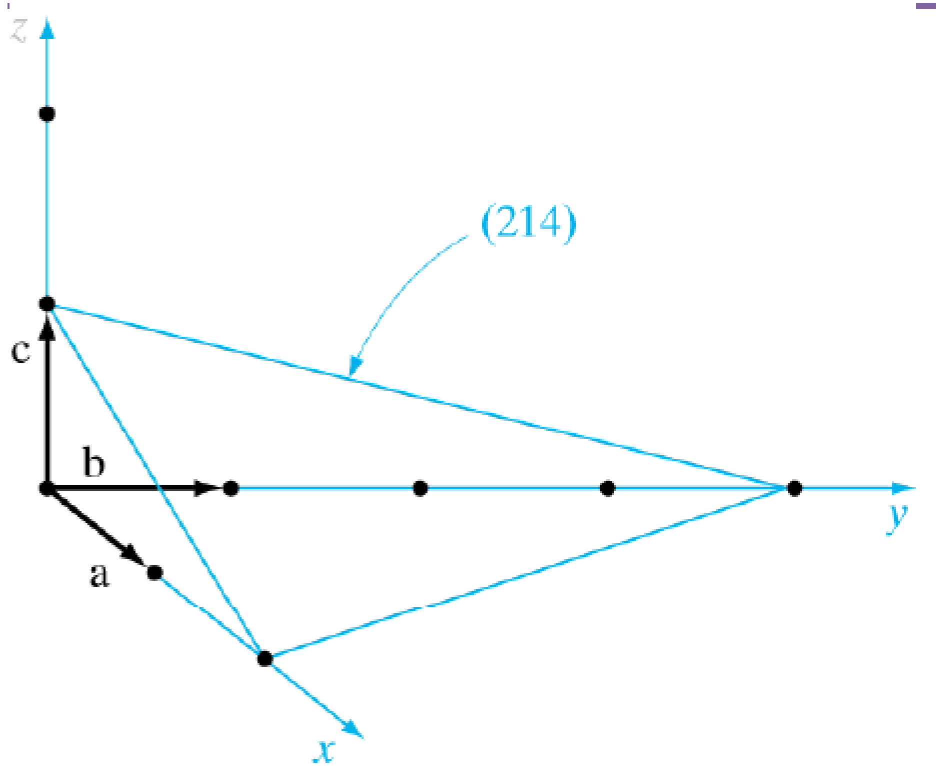


Miller Indices

(Intercept values are in multiples of the lattice constant; h, k and l are reduced to 3 integers having the same ratio.)

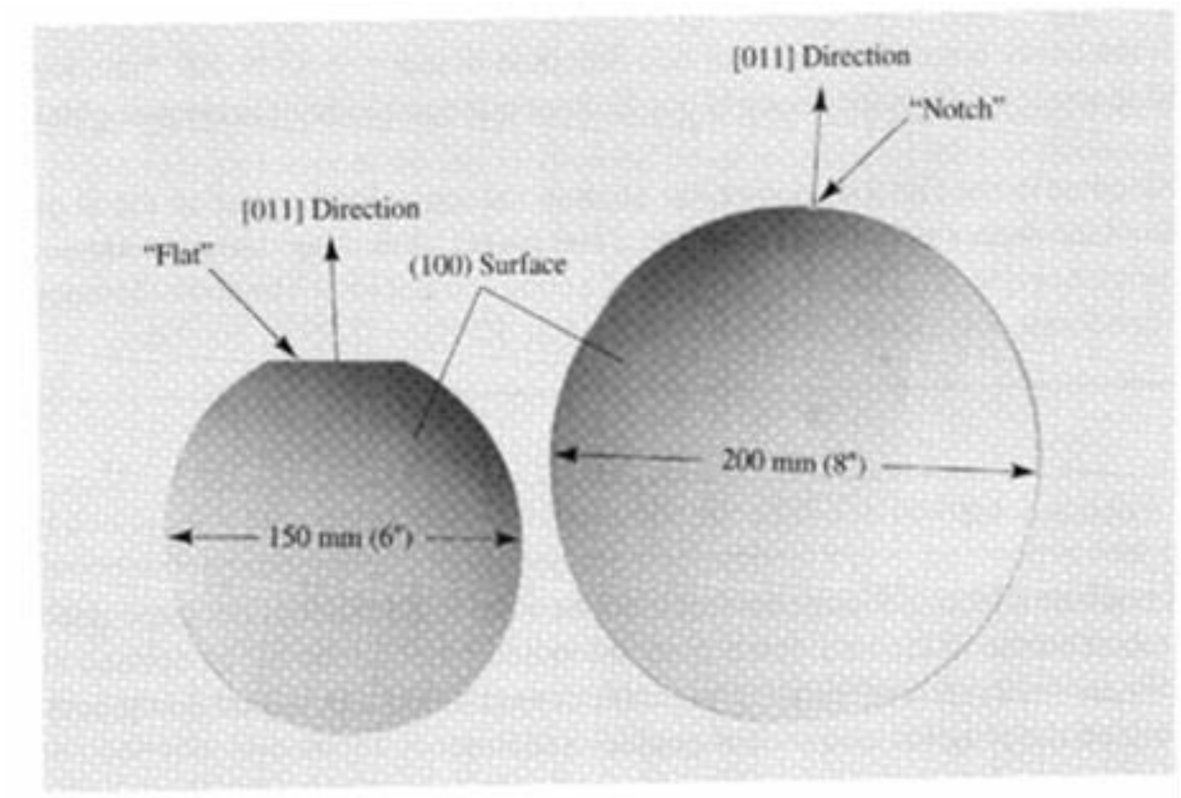
Notation	Interpretation
$(h\ k\ l)$	crystal plane
$\{h\ k\ l\}$	equivalent planes
$[h\ k\ l]$	crystal direction
$< h\ k\ l >$	equivalent directions

h: inverse x-intercept of plane
k: inverse y-intercept of plane
l: inverse z-intercept of plane

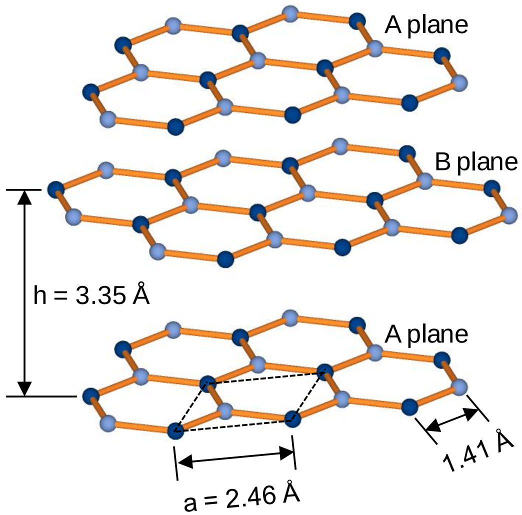


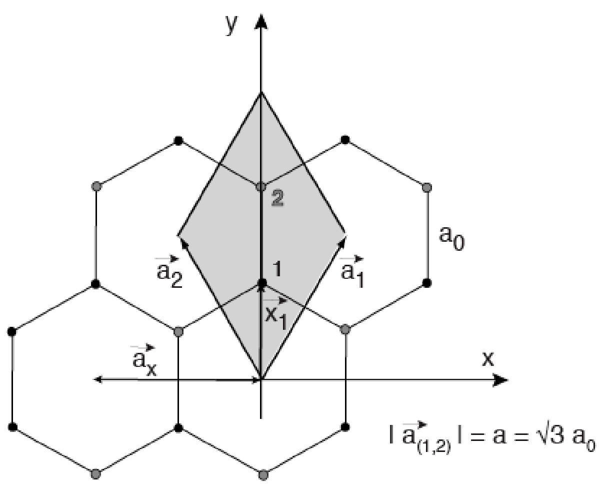
A (214) crystal plane.

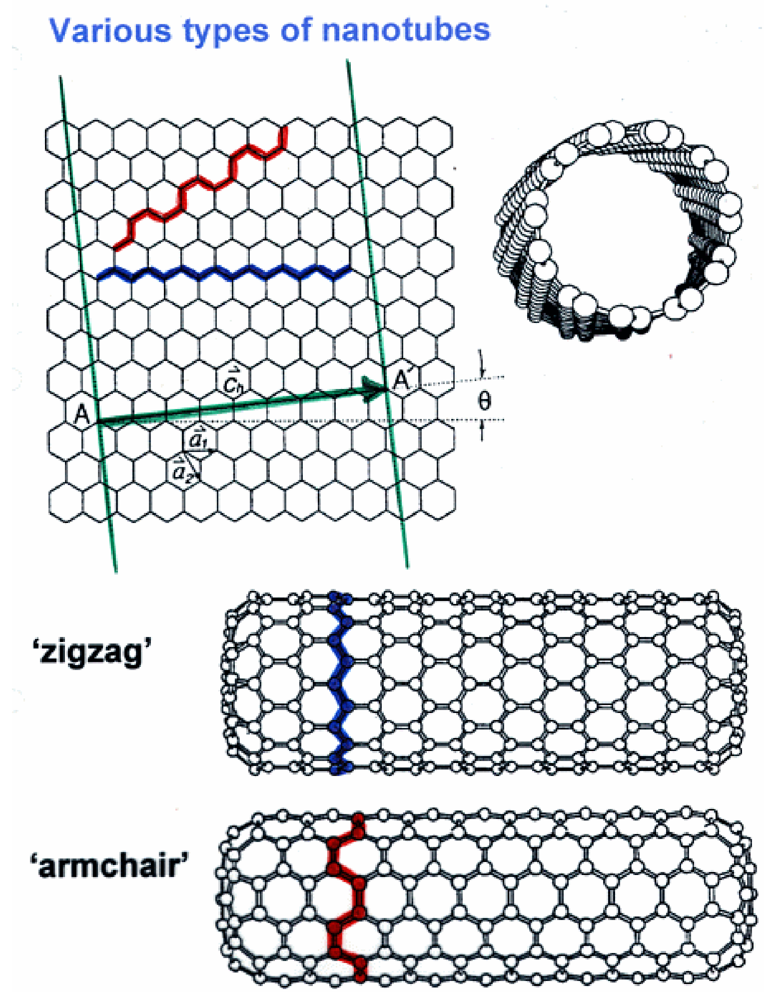
- Si wafers usually cut along {100} plane with a notch or flat side to orient the wafer during fabrication



- Graphite (~pencil lead) = parallel sheets of graphene
- Carbon nanotube = rolled up sheet of graphene







The Scale of Things – Nanometers and More