

ECE 635

Advanced Semiconductor Devices

Gong Gu

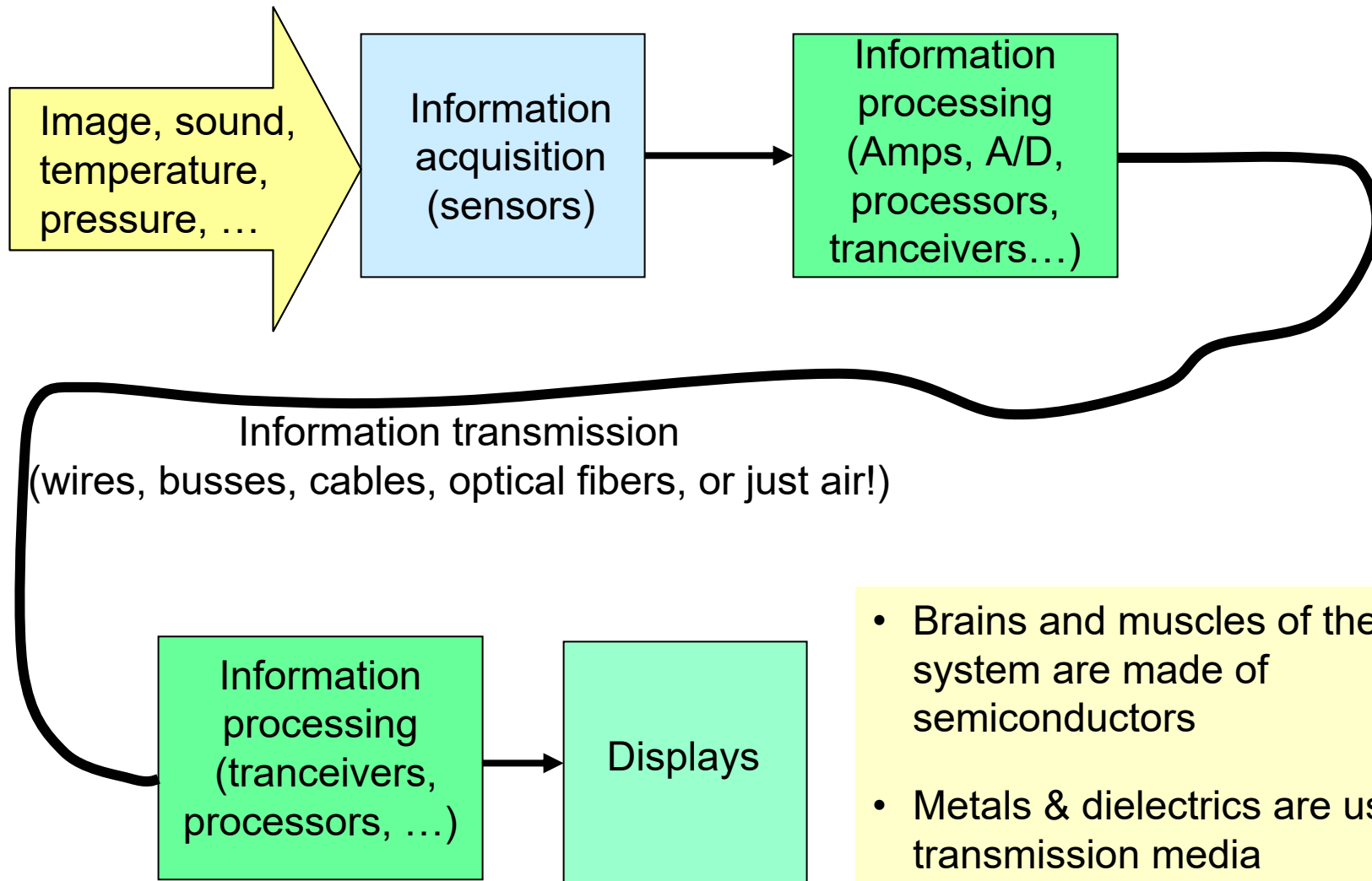
Course website:

<http://web.eecs.utk.edu/~ggu1/files/GradHome.html>

Fall 2017

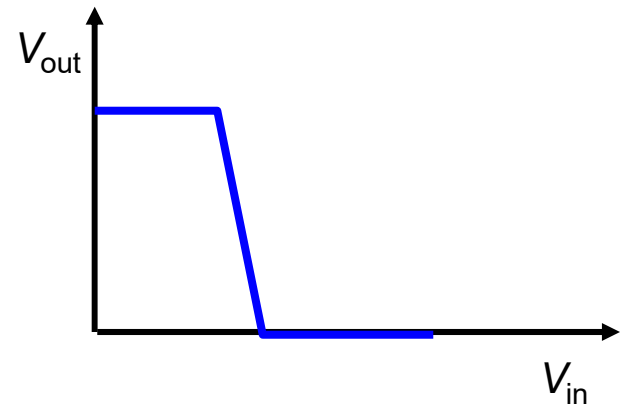
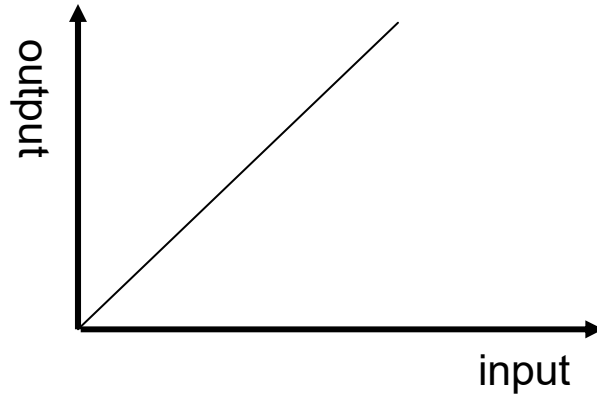
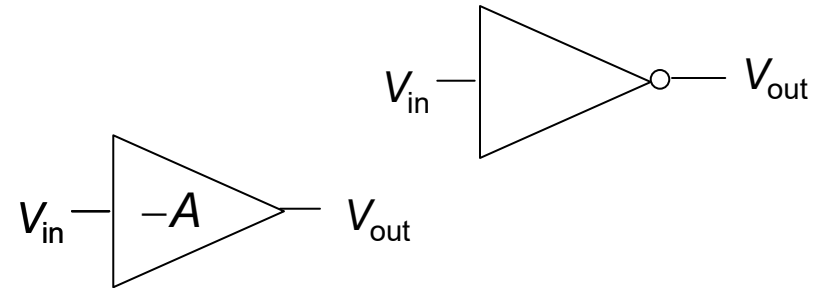
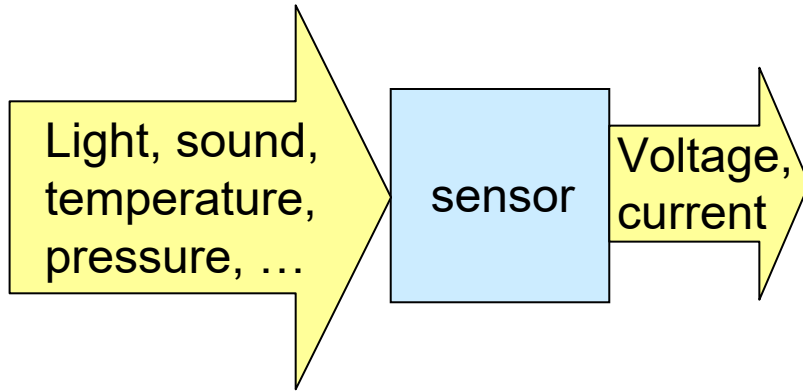
Why Semiconductors?

Sometimes we say “solid state”



- Brains and muscles of the system are made of semiconductors
- Metals & dielectrics are used as transmission media
- Why?

What's common for all the core components?

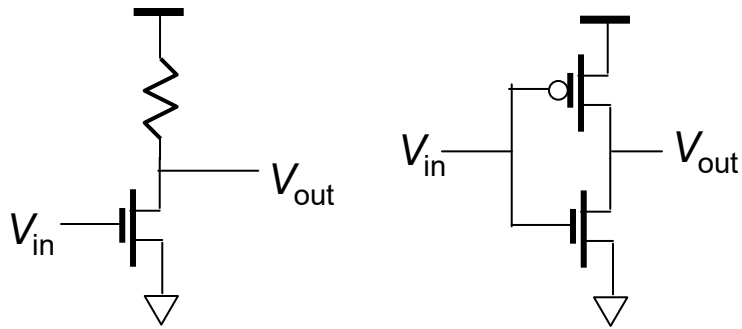


Modulation of some physical quantity (output) by some others

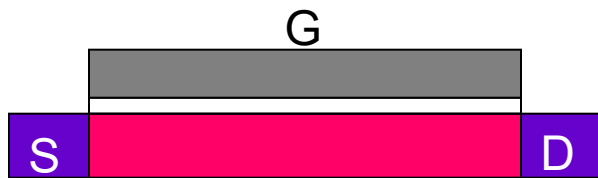
Some kind of gain, conversion ratio, sensitivity, etc

Example: Field-Effect Transistors (FETs)

Semiconductor vs Metal



FET's are building blocks.



Schematic illustration of a FET

For SiO₂ dielectric, breakdown field $E_b \sim 10^7$ V/cm. No matter how thick it is, the maximum induced carrier area density is $\epsilon_r \epsilon_0 E_b / q = 2 \times 10^{13}$ /cm². (Recall Gauss's law)

For a 1 μ m thick Si channel, $n_i = 1.45 \times 10^{10}$ /cm³, the background carrier area density is $n_i \times 10^{-4}$ cm = 1.45×10^6 /cm².

In principle, the area carrier density, and therefore the channel conductance, can be modulated by 7 orders of mag!!!

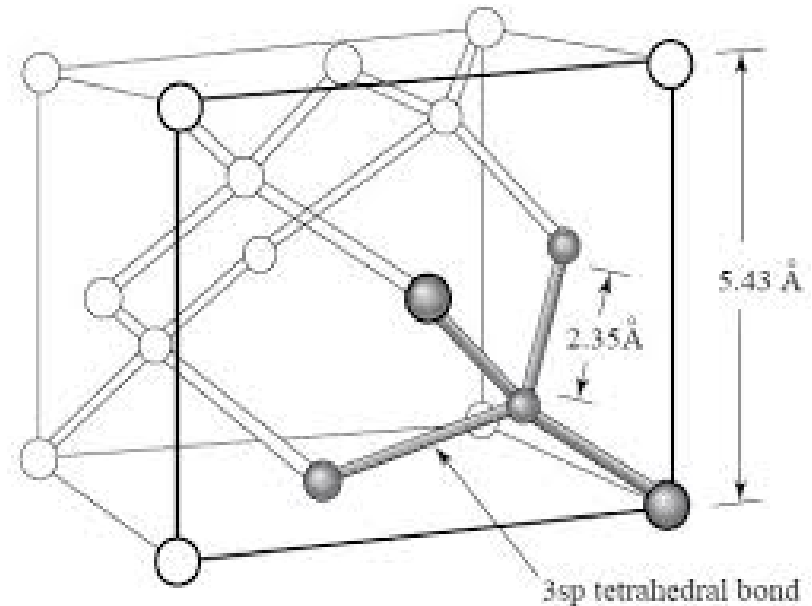
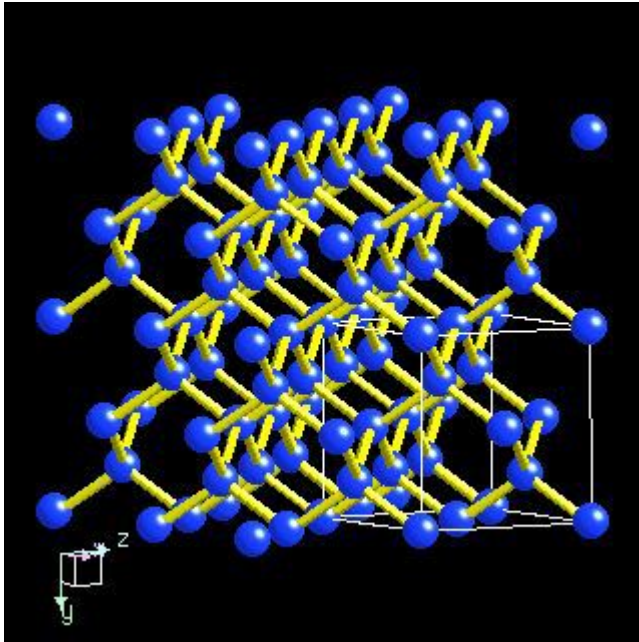
(Si's next-door neighbor in the periodic table)

For Al, $n = 1.8 \times 10^{23}$ /cm³. Even for 1 nm thin (monolayers!) Al, the background carrier area density is 1.8×10^{16} /cm². The conductance can only be modulated by 0.1%!!!

What are semiconductors, anyway???

What are semiconductors, anyway???

Crystal structure of Si



http://www.webelements.com/silicon/crystal_structure.html

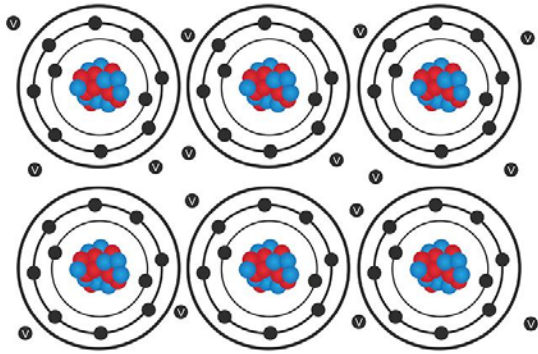
<http://onlineheavytheory.net/silicon.html>

- Take Si as example: work horse of the semiconductor industry
- Regular, periodic
- Each Si atom are bonded to 4 neighbors

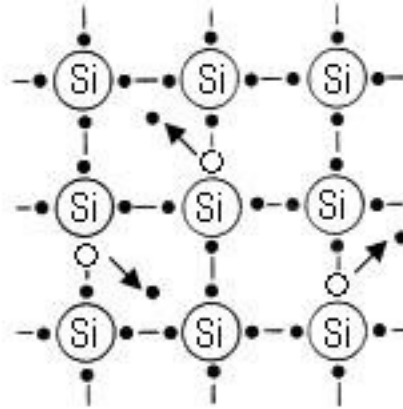
Si: $Z = 14$, $1s^2 2s^2 2p^6 3s^2 3p^2$, group IV

What are semiconductors??? -- Simplified pictures

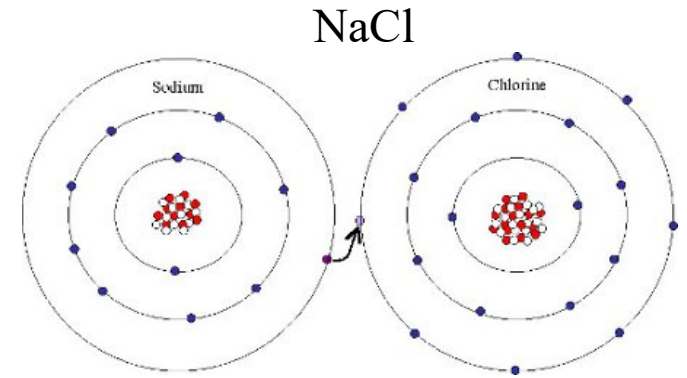
Bond picture



<https://infogr.am/how-does-bond-structure-affect-melting-point>

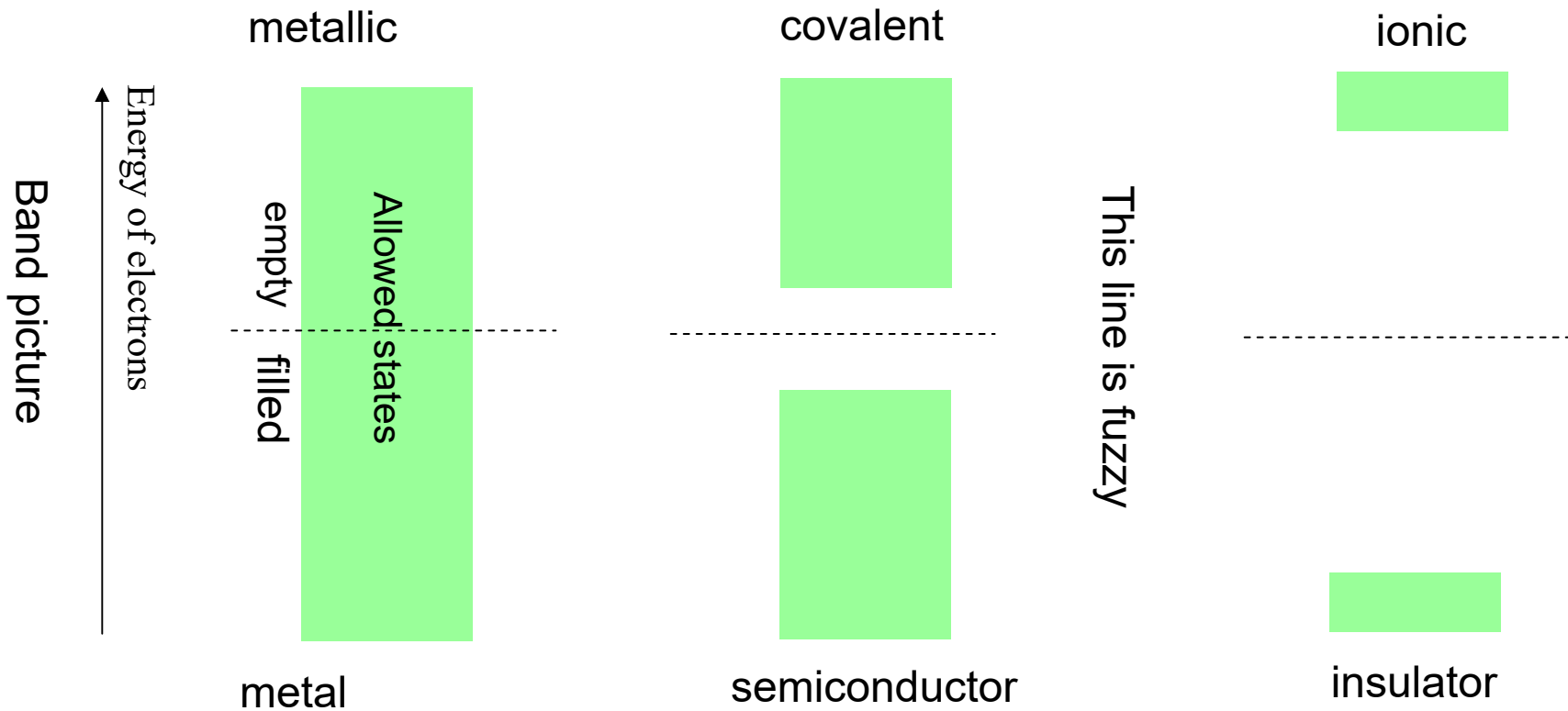


<https://keterehsky.wordpress.com/2010/03/10/9-2-semiconductor-diod/>

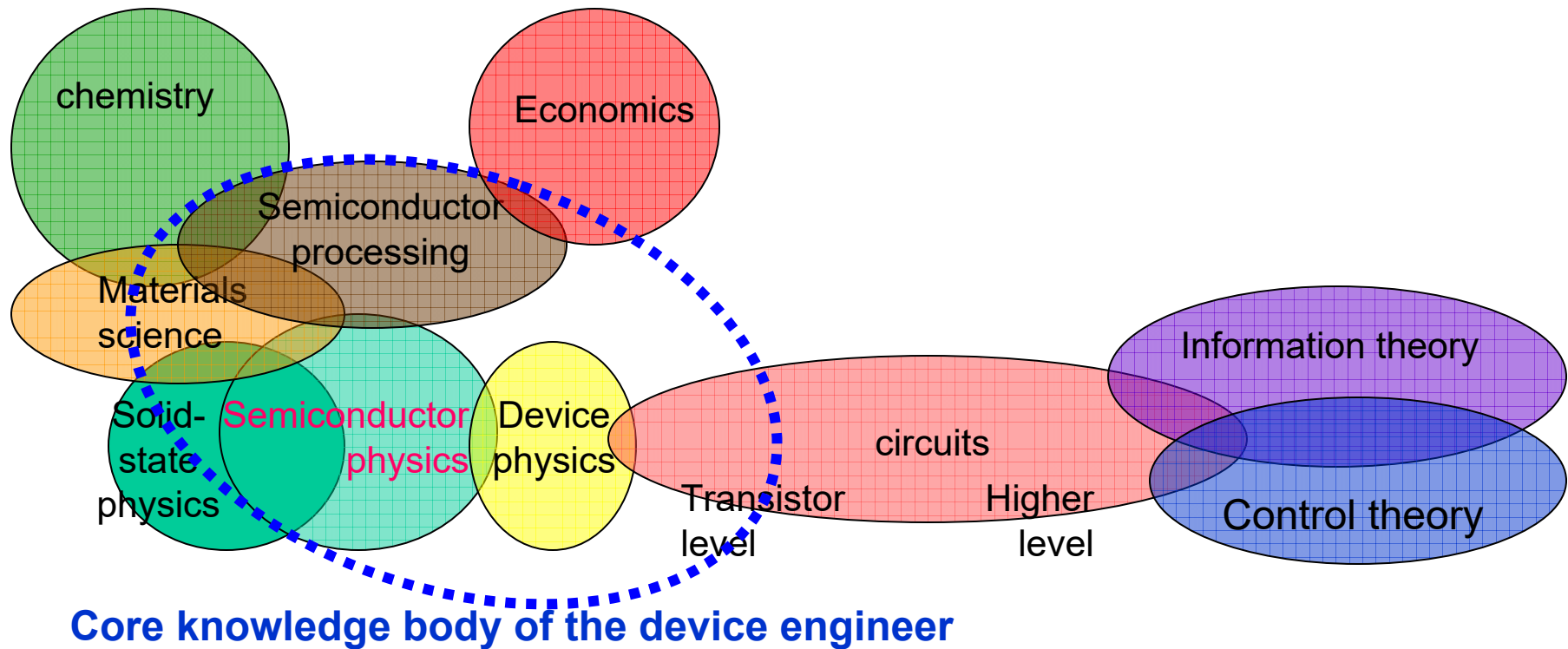


<http://knowledgebase.lookseek.com/Chemistry-Bonds-Ionic-Bonding.html>

Metal: "electron gas"

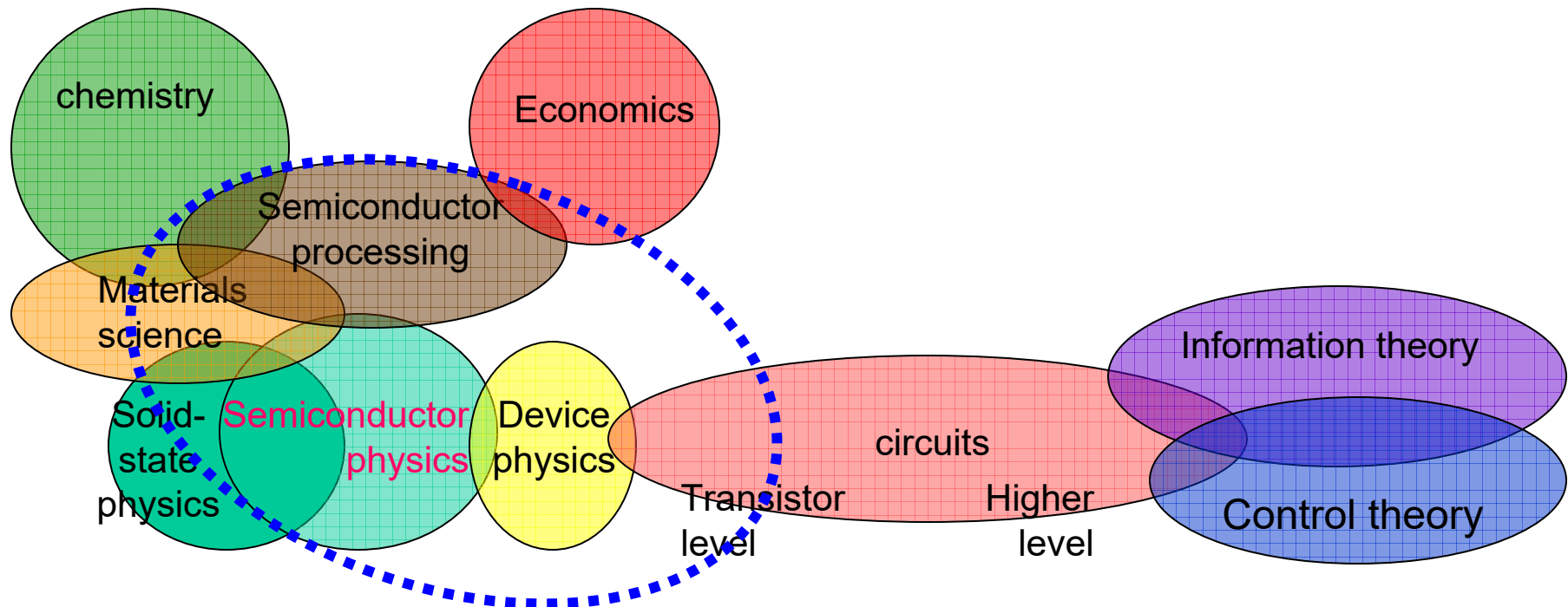


A Digression: The Vast Field of Electrical Engineering



- Different disciplines are different levels of extraction
- Device engineers are at the junction of many disciplines
- Follow your passion

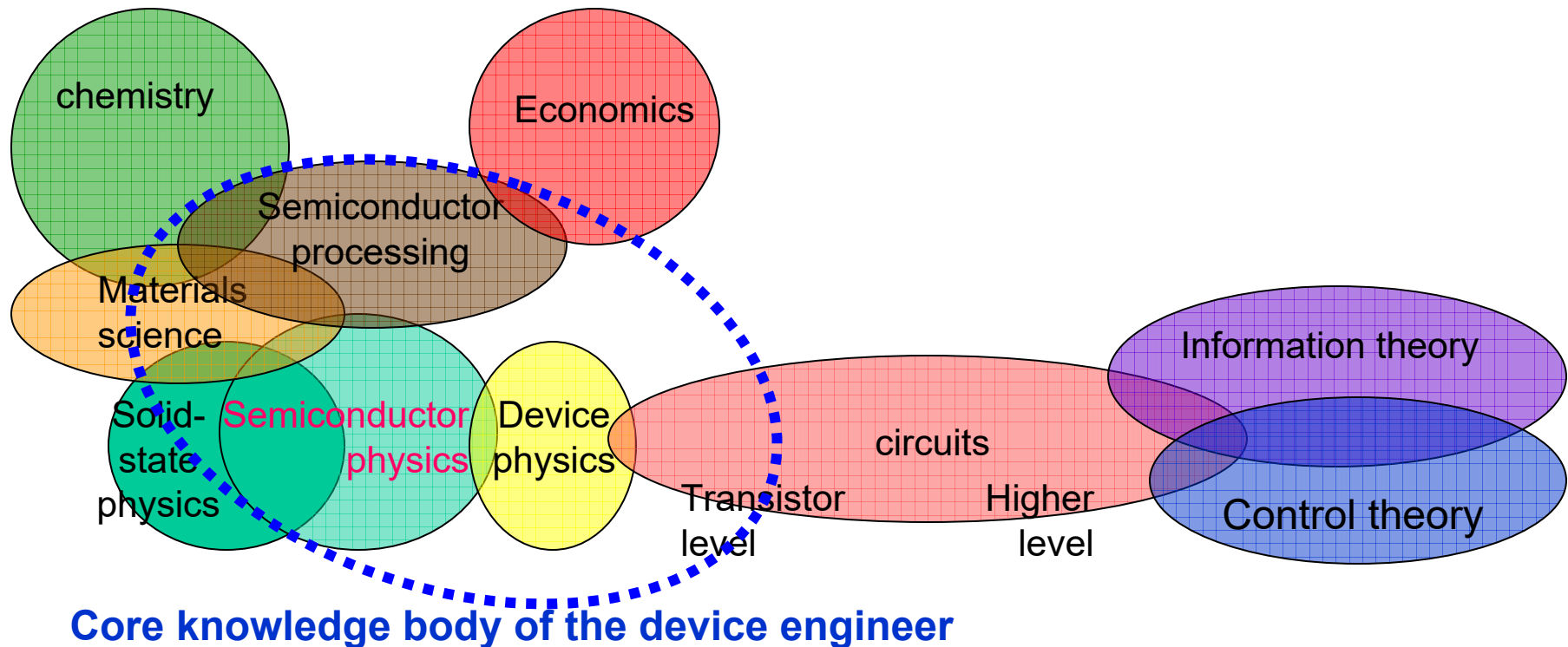
A Digression: The Vast Field of Electrical Engineering



Core knowledge body of the device engineer

- But, each small field can consume one's entire life
- So, how can one be a good device engineer???

A Digression: The Vast Field of Electrical Engineering



How can one be a good device engineer???
The big picture!

This course is about the big picture.

This course is tailored to suit your research interest.

Let's get to know each other!

- Name, year
- Previous exposure to quantum mechanics, solid-state physics, device physics, processing, ckt design (courses + hands-on)
- Advisor
- Research field, particular topic
- Like it?

Class meeting schedule

Syllabus

Course Objective:

To provide students with an understanding of device physics and advanced semiconductor device concepts.

Topics

- Review of Semiconductor physics
 - Crystal structure, band structures, band structure modification by alloys, heterostructures, and strain
 - Carrier statistics
 - Scattering, defects, phonons, mobility, transport in heterostructures
- Device concepts
 - pn junction
 - MOSFETs, MESFETs, MODFETs, TFTs
 - Heterojunction bipolar transistors (HBTs)
 - Semiconductor processing
 - Photodiodes, LEDs, semiconductor lasers
 - Introduction to nanoelectronics

This is the bottom-up approach. We will take a different approach.

Syllabus (Cont'd)

Reference books

- Jasprit Singh, *Physics of Semiconductors and Their Heterostructures*
Reads like somebody's notes. May not be the most elegant or strict from a physics point of view, but definitely serves semiconductor folks well. Intriguing and stimulating.
- Jasprit Singh, *Semiconductor Devices: Basic Principles*
Book by the same author on Devices but including semiconductor physics & processing.
- U. K. Mishra & J. Singh, *Semiconductor Device Physics and Design*
E-book available on line thru UT Lib.
- Karl Hess, *Advanced Theory of Semiconductor Devices*
Thin, but covers lots of stuff at advanced levels
- Ben Streetman, *Solid State Electronic Devices*
From basic physics to device concepts. Oldie goodie.
- S. M. Sze (施敏), *Physics of Semiconductor Devices*
The "Bible" of device engineers. Not for beginners. Keep it in mind or on your shelf; an excellent reference book for your future career.
- R. S. Muller & T. I. Kamins, *Device Electronics for Integrated Circuits*
An undergrad textbook on Si microelectronics, but good to have. I go back to it quite often.
- J. D. Plummer, M. D. Deal, P. B. Griffin, *Silicon VLSI technology: fundamentals, practice and modeling*
Best textbook on processing, by the people who developed many of the models.

Syllabus (Cont'd)

Journals

- IEEE Electron Device Letters
- IEEE Transactions on Electron Devices
- Applied Physics Letters
- Journal of Applied Physics

Websites

- Wikipedia (Are you kidding? No!)
- Ioffe Physico-Technical Institute
 - <http://www.ioffe.ru/SVA/NSM/>
 - <http://www.ioffe.ru/SVA/NSM/Semicond/index.html>
 - Physical properties of many semiconductors.

Syllabus (Cont'd: The Tough Part)

Evaluation

- Classroom participation, performance (15%)
- Homework / Mini projects – simple (50%)
- Term paper: Review of a selected specific area, ~~oral presentation on the topic of the paper, oral exam~~ (35%)
- The good news: It's not that tough
 - ...
 - The population is not big. Any distribution does not have much statistical meaning. Which means, you could all get A's. On the other hand, you could ...

Back to Business

What are semiconductors, anyway???

What answers do you have now?

Long way to go to answer this question.

Homework 1

Calculate the values given in Slide 4 of this Introduction

1. Given a dielectric breakdown field $E_b = 10^7$ V/cm for a FET, calculate the maximum possible induced areal carrier density. Use Gauss's law. Give your rationale; show that this value is independent of the dielectric thickness.
2. For Si, the background volume carrier density is $n_i = 1.45 \times 10^{10}$ /cm³. What is the areal background carrier density for a 1 μ m thick slab of Si? Compare your answer to the above maximum induced carrier density. For how many orders of magnitude can you moderate the carrier density?
3. For Al, the volume carrier density $n = 1.8 \times 10^{23}$ /cm³. Assuming you *could* have 1 nm thin Al, what is the background carrier area density? Compare to the above maximum induced carrier density, and show that the conductance can only be modulated by 0.1%.

Note: We mostly use the SI units, where the unit for length is m. In semiconductor device physics, however, we customarily use cm for length. Make sure you get the unit right.

No hard deadline. But it's good to get it done before the semester gets really busy.

Review of Semiconductor Physics

Quantum mechanics

- Schrödinger equation
 - The equation that scared Einstein
- Stationary states
- Special case: free space
- E-k dispersion: light wave vs de Broglie wave
- The concept of eigenstates
- Wave packets
- The uncertainty principle

If we were to take a bottom-up approach, we would start with talking about these things, but we take a different approach this semester...