CHAPTER 3 : NANOELECTRONICS

In order to understand nanoelectronics, we need first to understand electronic materials (in general) and semiconductors, in particular. The latter enabled the miniaturization of the electronic transistor, which gave rise to the semiconductor revolution.

Show (slide 1-5) with a list of electronic materials and discuss them shortly.

BAND STRUCTURE AND OTHER PECULIARITIES TO UNDERSTAND SEMICONDUCTORS

- Semiconductors vs. conductors : Conductivity decreases when decreasing temperature. This points to an intrinsic difference btw these materials.

- Electronic structure and Pauli exclusion principle.

  An atom is defined by four quantum numbers

  n = principal
  l, m = angular momentum (orbital)
  s = spin

  slide 6 - H atom

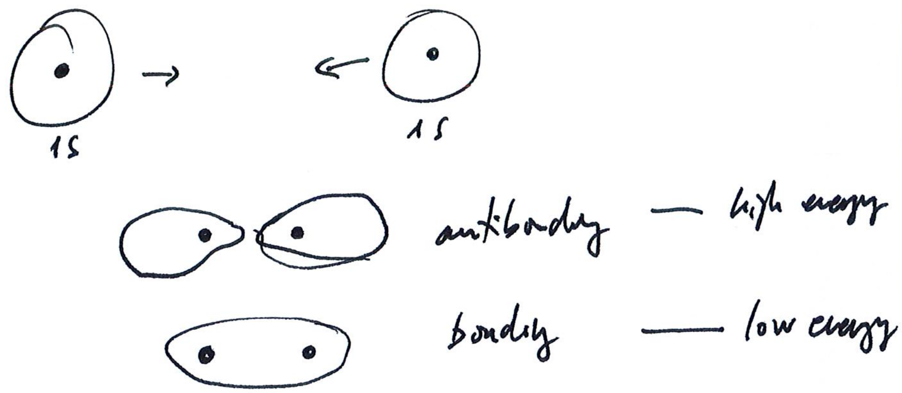
  s - 2 electrons
  p - 6
  d - 10
  f - 14

  According to Pauli, two electrons cannot be in the same exact state. So if they are in the same orbital, they need to have opposite spin.

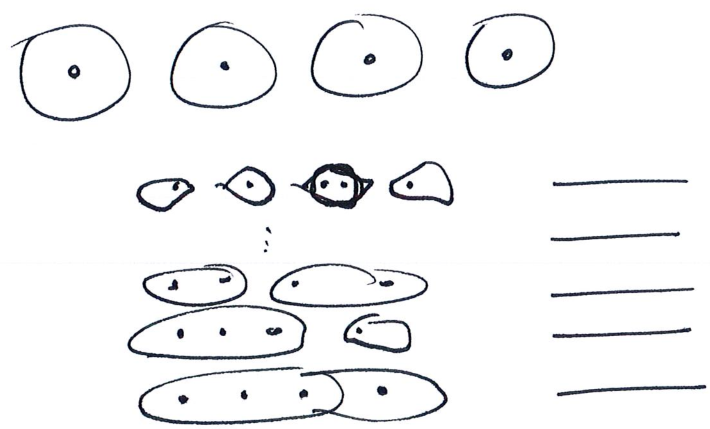
- Types of solids :
  * Ionic and covalent : low conductivity - high interactions btw atoms (>4eV
  * Metallic : high conductivity - low interactions (~1-4 eV) Atoms have unfilled orbitals (valence) which become delocalized and lead to conduction.

- Band theory (Example with Na in book, but could be done with any atom).

  - 2 atoms of H:

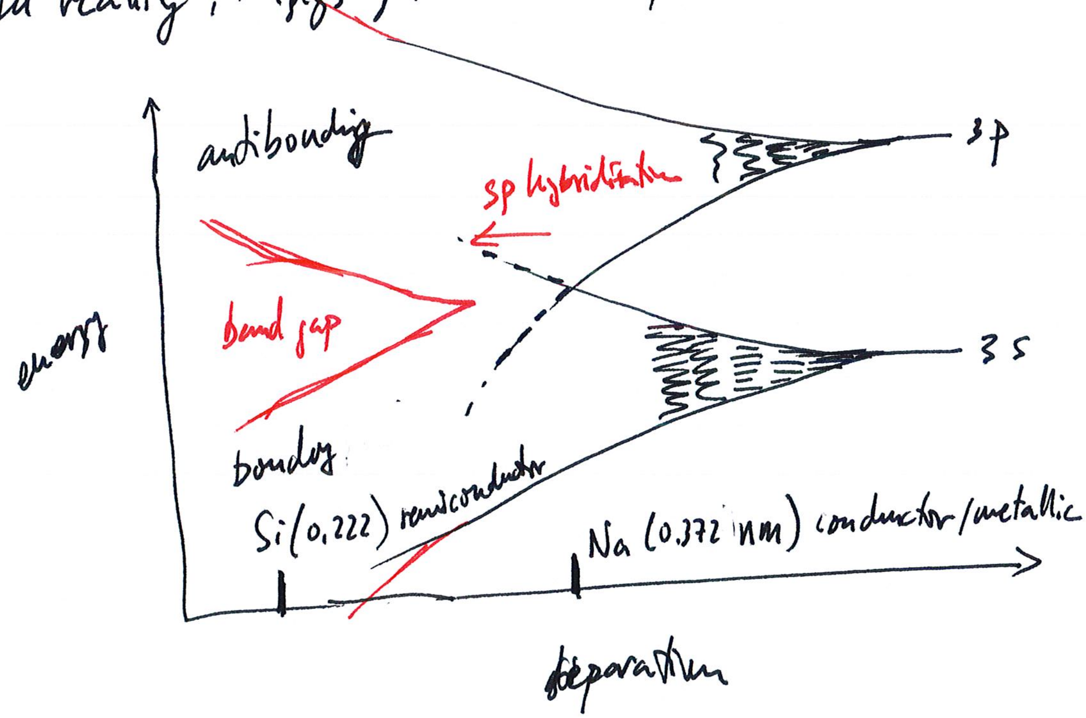


  - 4 atoms of H:



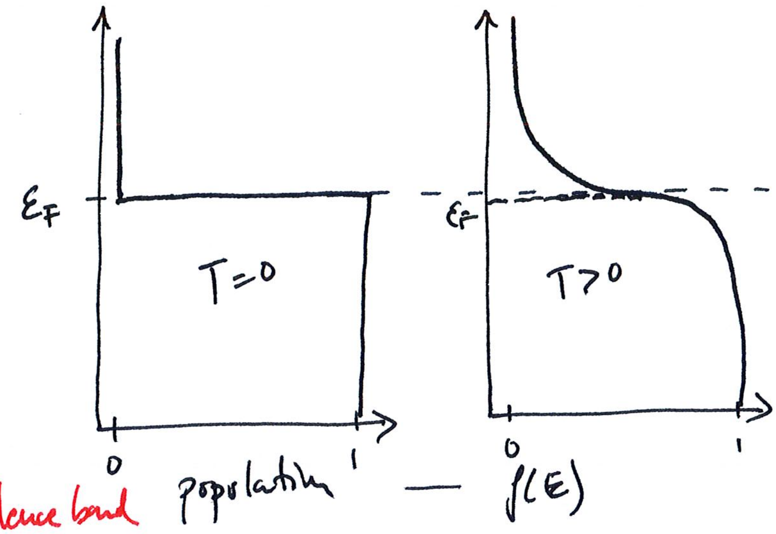
show slide 7

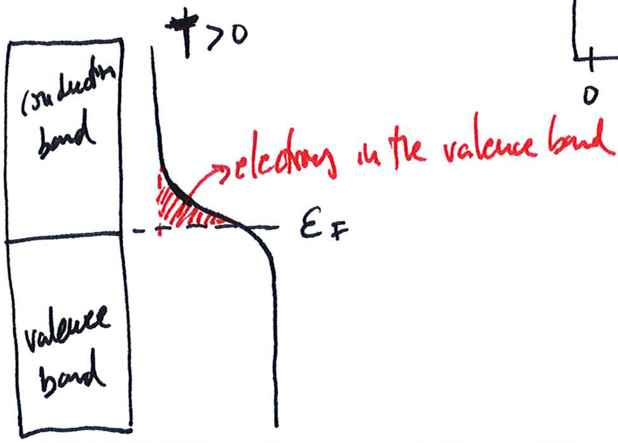
In reality, things get more complicated:

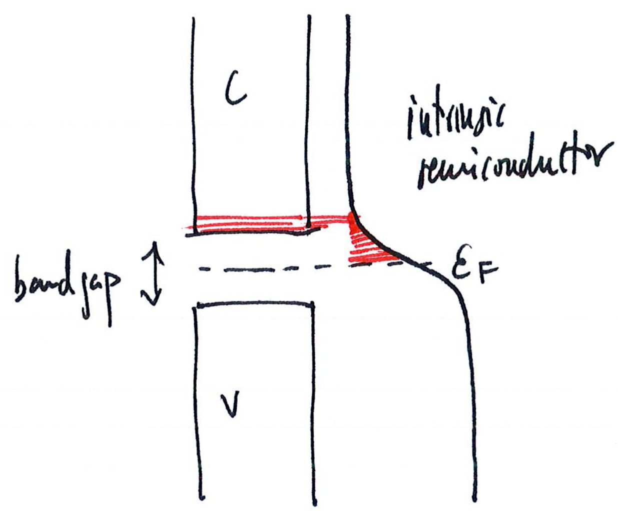


- Fermi energy (for electrons, fermions) - particles with $s=\frac{1}{2}$, obeying Pauli-exc. p.

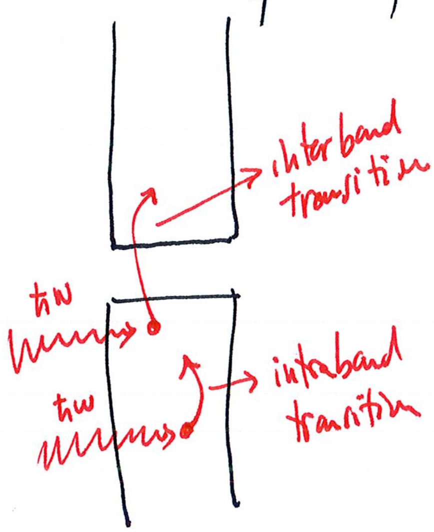
$$f(E) = \frac{1}{e^{[(E-E_F)/k_BT]}+1}$$







optical response in semiconductors



this is what differenciates conductors from insulators.

Examples of conductors / insulators:

- Neon: Last band filled (even number of electrons) $2s^2 2p^6$
  separation btw valence and conduction band 20 eV
  at 300 K $\rightarrow$ $k_B T = 25$ meV $\Rightarrow$ no population in conduction band
  Excellent insulator

- Sodium (mixed 3s/3p bands, partially filled) $3s^1$ just one "free" electron
  The band is partially filled, so a little bit of energy can be given to the electron and lead to conduction

table of excellent conductors:

Al	13 e^-	$3s^2 3p^1$
Cu	29 e^-	$3d^{10} 4s^1$
Ag	47 e^-	$4d^{10} 5s^1$
Au	79 e^-	$4f^{14} 5d^{10} 6s^1$

all only have $1e^-$ in the last band.
those are the best conductors.

SEMICONDUCTORS

Are insolators with a small bandgap Si: [1.1 eV], Ge [0.7 eV]

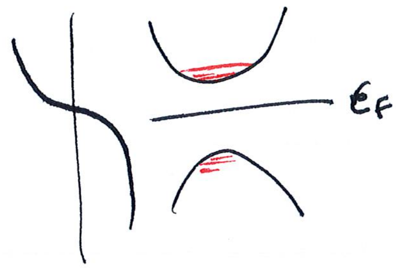
show slide 8 with different semiconductors (Direct-indirect gap)

- Direct bandgap SC: Electron/holes recombination without loss of momentum, followed by an emission of a photon.
  APPLICATIONS: Light-emitting diodes and lasers

- Indirect bandgap SC: Direct transition is forbidden. Recombination is mediated by phonons (no photons)

Intrinsic semiconductor : Eg. Si, Ge...

No impurities. The number of electrons in the conduction band equals the number of holes in the valence band, what means that the Fermi energy is placed in the middle of the gap.



Extrinsic semiconductors : By doping with impurities

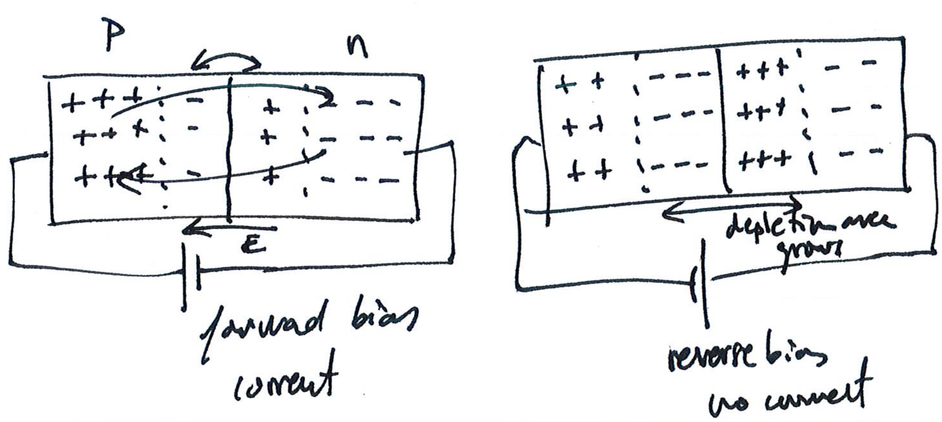
n-type : When a group IV element (Si/Ge) is doped with a group V element (P/As/Sb)
Four electrons of the impurity atom play the same role of four holes in the V_B of the host, but the fifth is unpaired. Donates electrons to the Si/Ge.
n-type -> n for negative charge carrier

p-type : A group IV is doped with a group III (In/Ga). Creates vacancies. Carriers are holes, positive charge (P)

In both cases, increasing doping concentration results in larger conductivity.

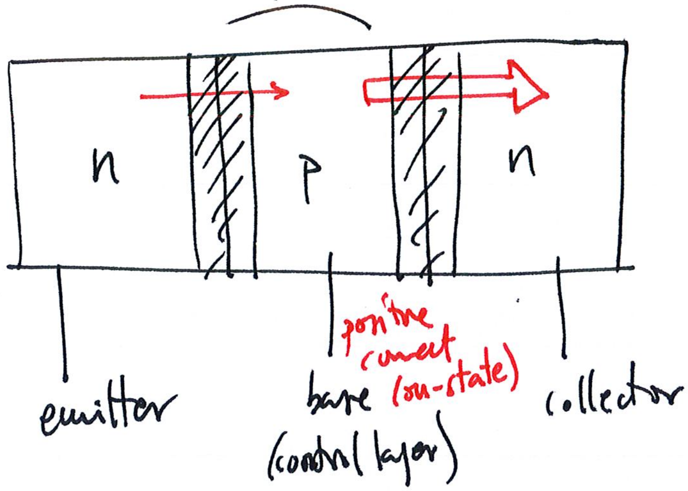
N/P (n/P) JUNTIONS:

show video of p/n junction and a solar cell



THE TRANSISTOR

opposed depletion areas (no current flows even with large bias voltage



or pnp

a voltage applied to the base provides means for the two barriers to be overcome and current conducts. Actually is amplified

Show slides 9 and 10

Finish chapter by talking about nanoscale electronics

- Single-electron transistors
- Perhaps graphene

Use powerpoint presentation