Before starting the lecture…

- Once again, this course is for the microelectronics.
  - It’s about the circuit analysis…
- What is the most important rule for the circuit analysis?
  - Kirchhoff’s current rule!
  - One example

Lecture1: Basic physics of semiconductor (1)

Sung-Min Hong (smhong@gist.ac.kr)

Semiconductor Device Simulation Lab.
School of Information and Communications
Gwangju Institute of Science and Technology

GIST Lecture on March 7, 2016 (Internal use only)

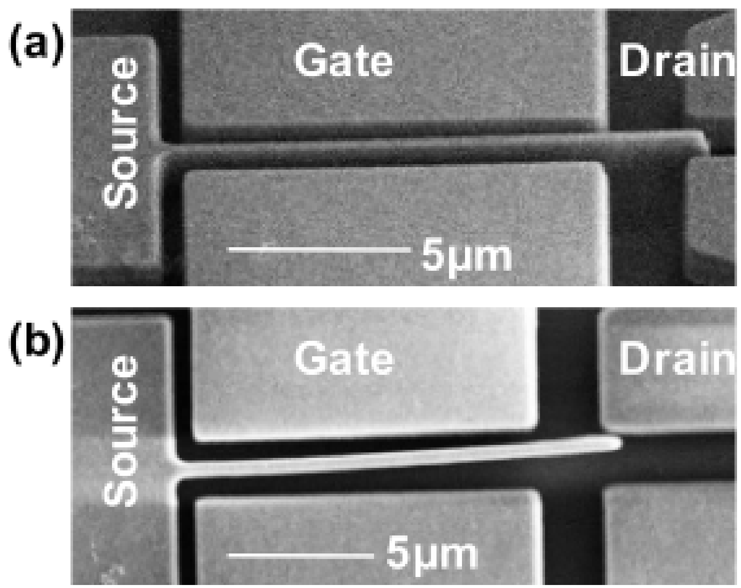
Electronic circuit

- Our course is not about the semiconductor physics.

- Why do we consider the basic physics of semiconductor?
  - Especially, silicon.

In principle,

- There can be various ways to realize a component in the electronic circuit.
  - Even without semiconductors!
- For example,
  - NEM relay



S. Chong et al., ICCAD, 2009

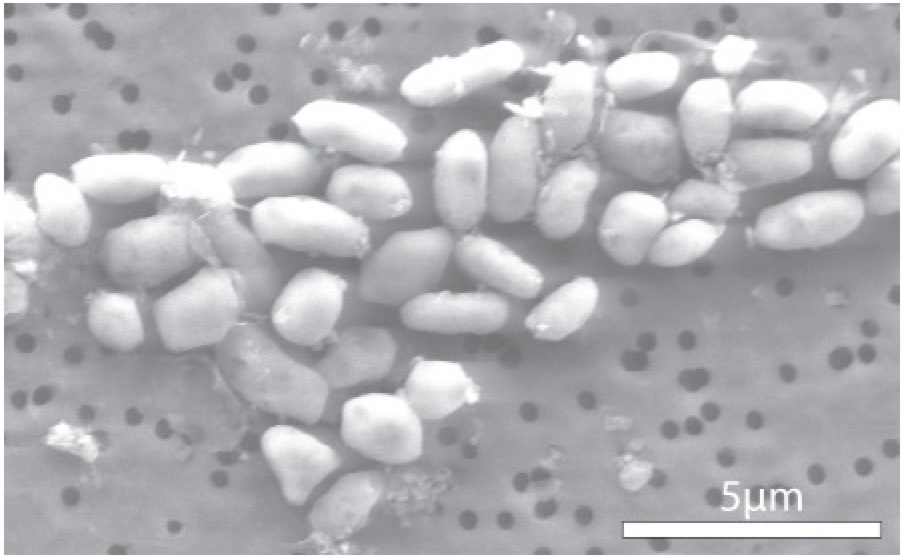
In reality,

- Currently, ***only semiconductor technologies*** can achieve the tough specifications required.
  - Performance
  - Power consumption
  - Reliability
  - Variability
  - And most importantly, cost!

- That's the reason why we first study the semiconductors.

Analogy

- SF writers sometimes imagine that the carbon-based life is not the only form of the living creature.

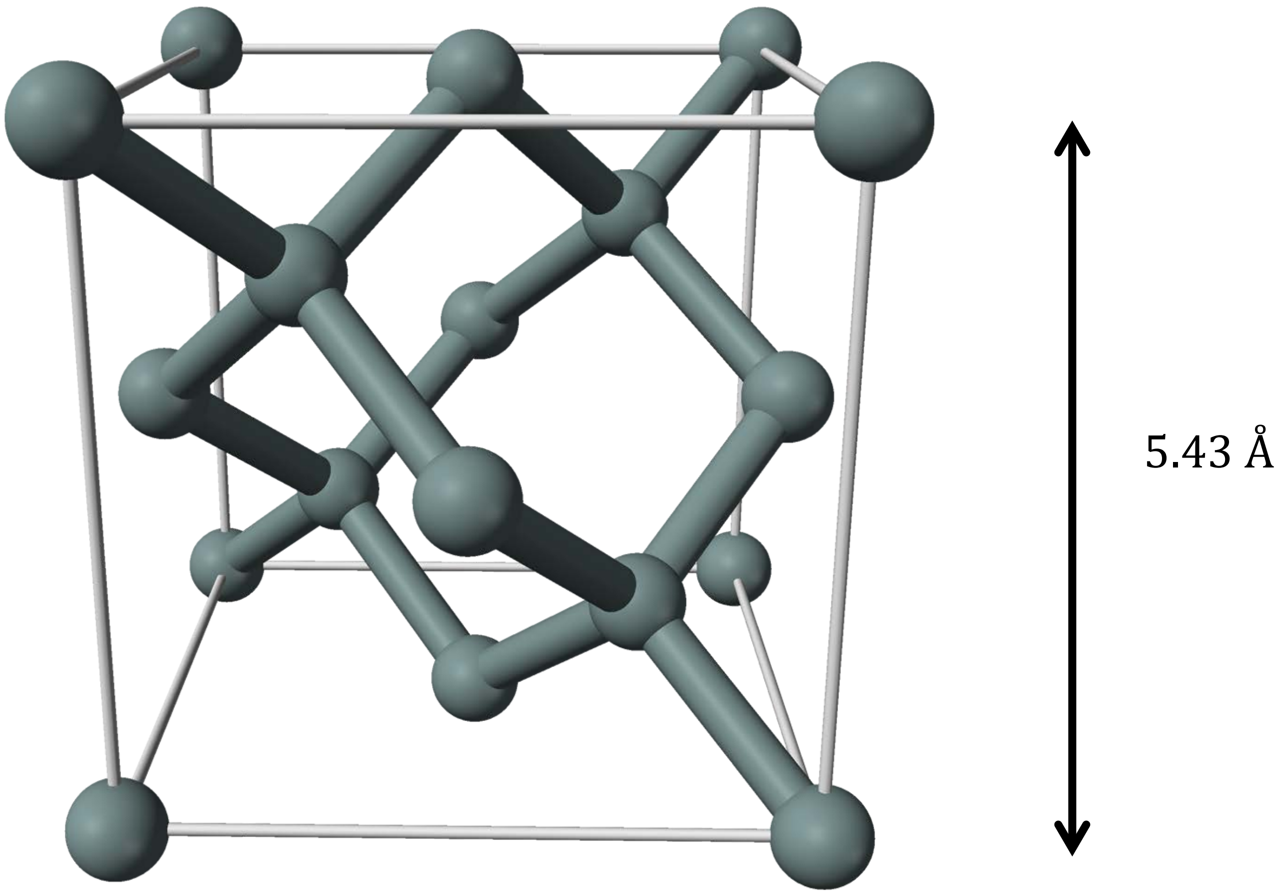


Magnified cells of bacterium GFAJ-1 (Wikipedia)

- However, in reality?

Crystal structure of Si

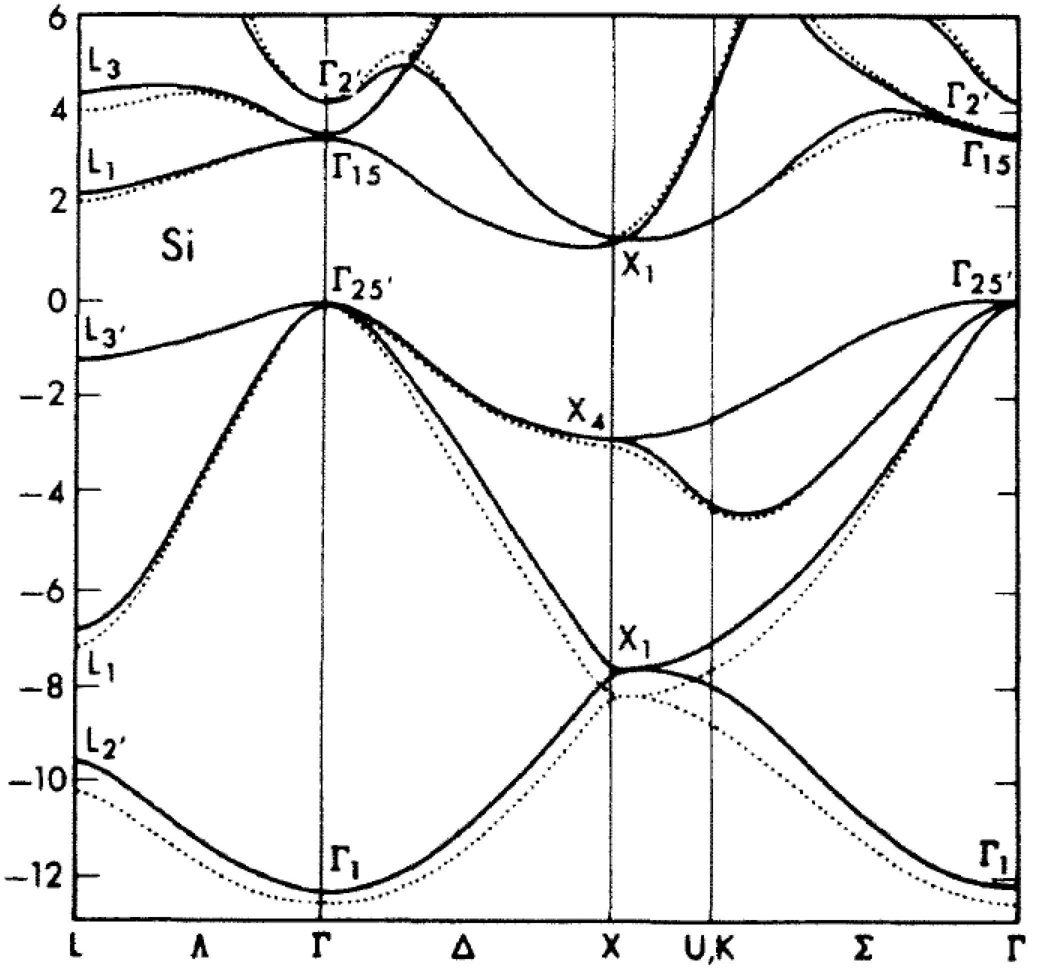
- Diamond cubic crystal structure



Taken from Wikipedia

Band structure

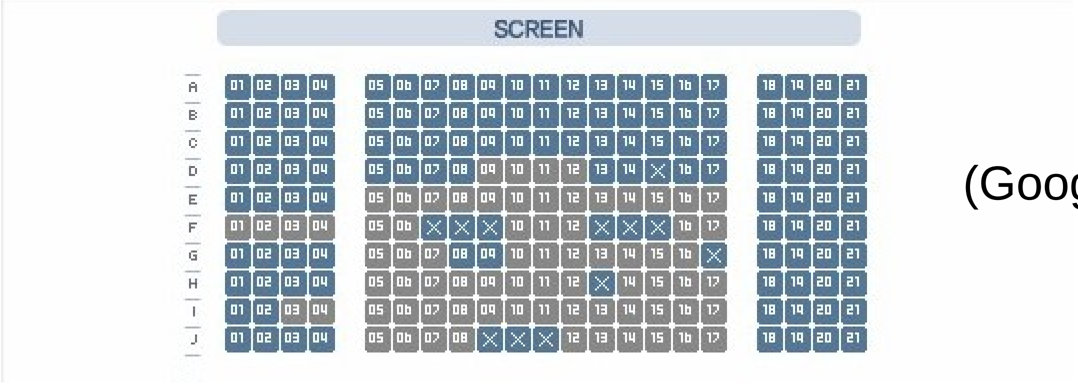
- Band structure of silicon (Band gap ~ 1.12eV)



(J. R. Chelikowsky and M. L. Cohen,
PRB, vol. 14, p. 556, 1976)

Reservation of seats

- In a movie theater,
  - Assume that you must reserve several movie tickets for your group members.
  - They are not rich at all.
  - Different seats with different prices!



(Google Image)

- In this analogy,
  - Price = energy

I-680 (a *free*way in California)

- (Google image)

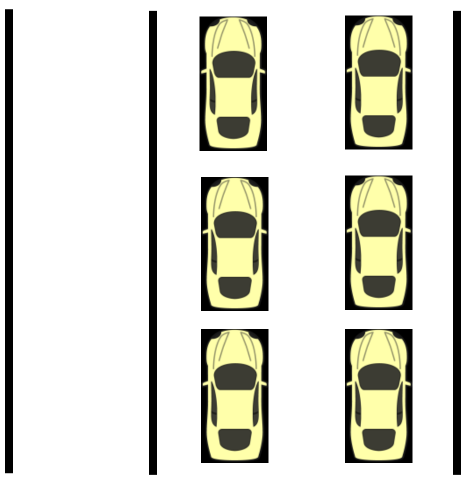
NOT free.
Almost empty.
Fast.

Free.
Crowed.
Slow.

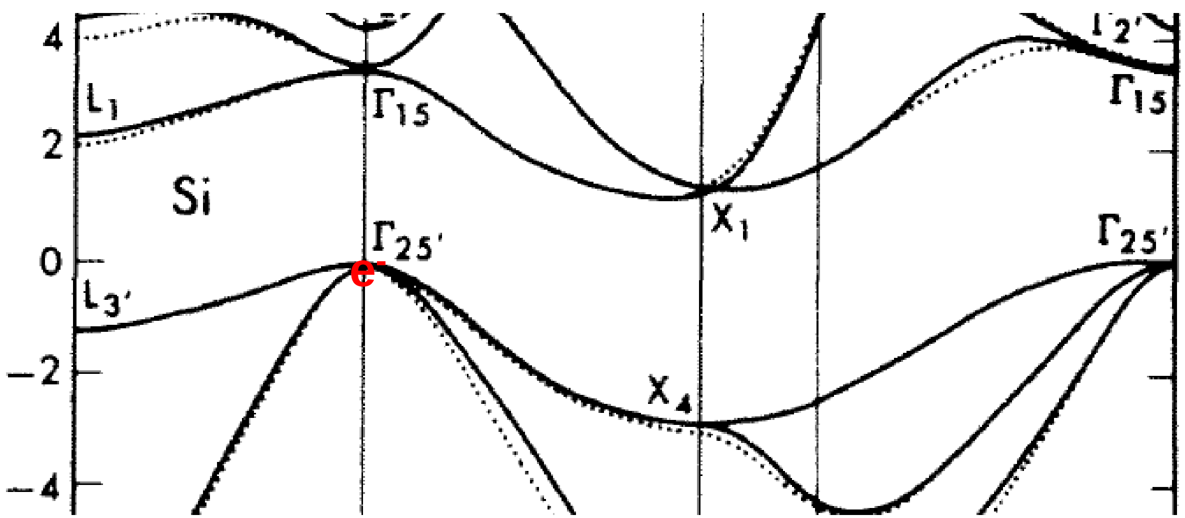
- Once again, in this analogy, fare = energy
  - Then, who pays?

Thermal energy

- At higher temperatures, electrons gain thermal energy.
  - The covalent bonds are broken.
  - They act as free charge carriers.



(Google Image)



Go-stones

- Concept of holes
  - When freed from a covalent bond, an electron leaves a “void” behind.
  - It – the void – is called a “hole.”

Go-stones
(Google Image)

- Electrons and holes are charge-carriers.

Intrinsic carrier density

- At higher temperatures,
  - There will be a certain amount of electrons and holes.
  - How many “free” electrons? (Assume the intrinsic material.)
  - It is the meaning of the intrinsic carrier density, n_i.

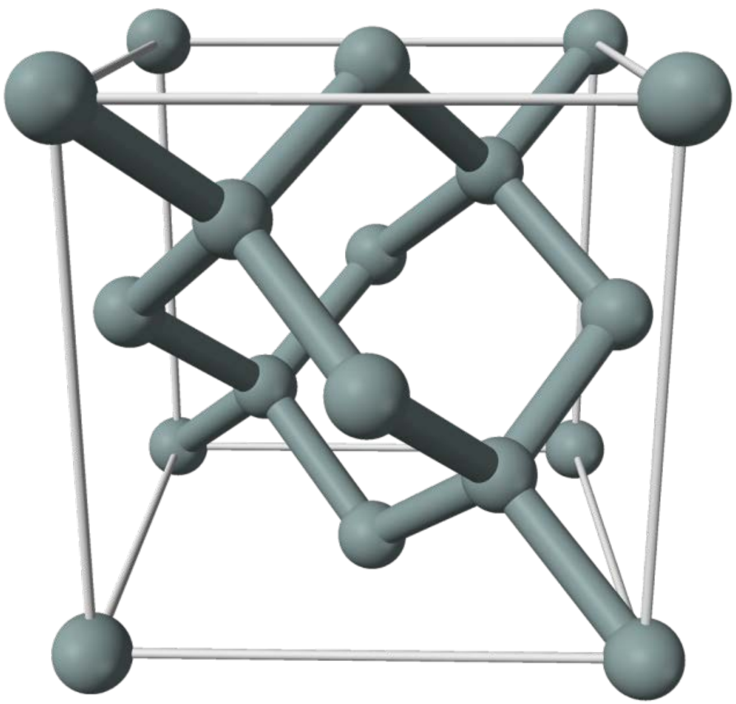
- Expression of n_i

$$n_i = 5.2 \times 10^{15}\, T^{1.5} \exp \frac{-E_g}{2k_B T} \quad [electrons/cm^3]$$

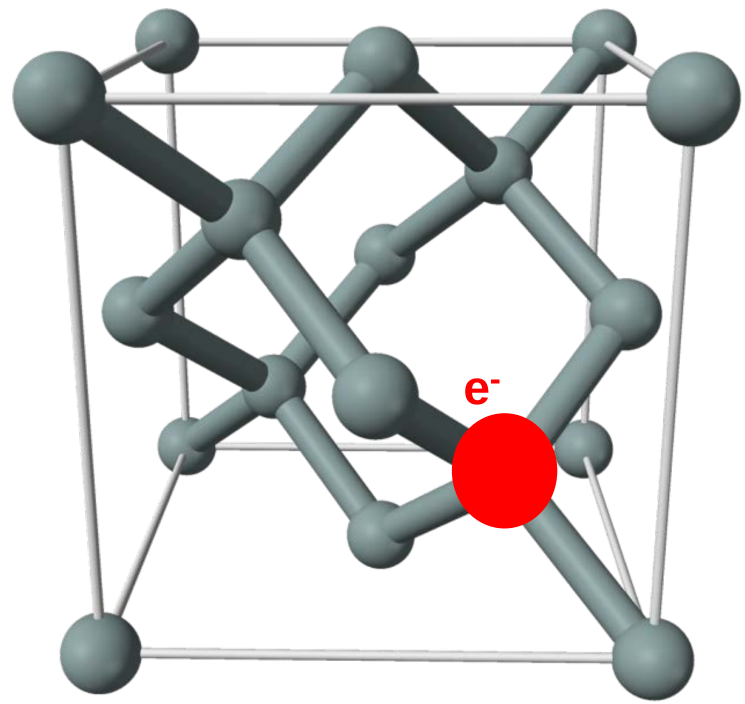
  - Boltzmann constant, k_B
  - At 300K, n_i is roughly 10^{10} $[electrons/cm^3]$.

Impurity atom

- The phosphorus atom has 5 valence electrons.
  - Additional electron (e^- in the right figure) serves as a charge carrier.



Pure silicon



Silicon with “impurity” atom
(For example, phosphorus)

Impurity atoms

- One impurity atom contributes a "free" electron.
  - If 2 (, 3, 4, 5, …) phosphorus atoms are introduced?
  - 2 (, 3, 4, 5, …) additional electrons will be generated!
- More specifically,
  - When the density of the phosphorus atom is $N\ [atoms/cm^3]$,
  - The electron density becomes $N\ [electrons/cm^3]$.
- Typical value? (Feeling about the numbers)
  - $10^{15}\ [atoms/cm^3]$: Almost no impurity
  - $10^{17}\ [atoms/cm^3]$: Low (or moderate) impurity density
  - $10^{19}\ [atoms/cm^3]$: High impurity density (Not extremely high)
- What is it good for?
  - Conductivity can be changed drastically.

n-type? p-type?

- Phosphorus has 5 valence electrons.
  - Therefore, it contributes an electron.
  - n-type
- Boron has 3 valence electrons.
  - It cannot provide 4 valence electrons to complete 4 bonds.
  - Instead, it contributes a hole.
  - p-type

Minority carrier density

- Majority vs. minority
  - In the n-type semiconductor, electrons are majority carriers.
  - On the other hand, holes are minority carriers.

  - At equilibrium,

$$np = n_i^2$$

Nonequilibrium

- Up to now, we have considered the equilibrium case.

- Various ways to generate the nonequilibrium cases:
  - Electric potential difference
  - Others?

- Result?
  - Flow of charged particles!