Primer on Semiconductors

Unit 1: Material Properties

Lecture 1.7: Unit 1 Recap

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Semiconductors

metal

gold (Au)

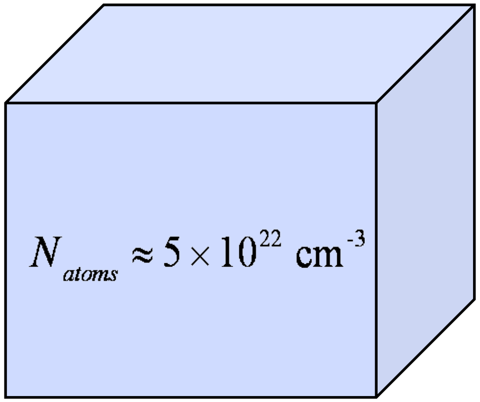
semiconductor

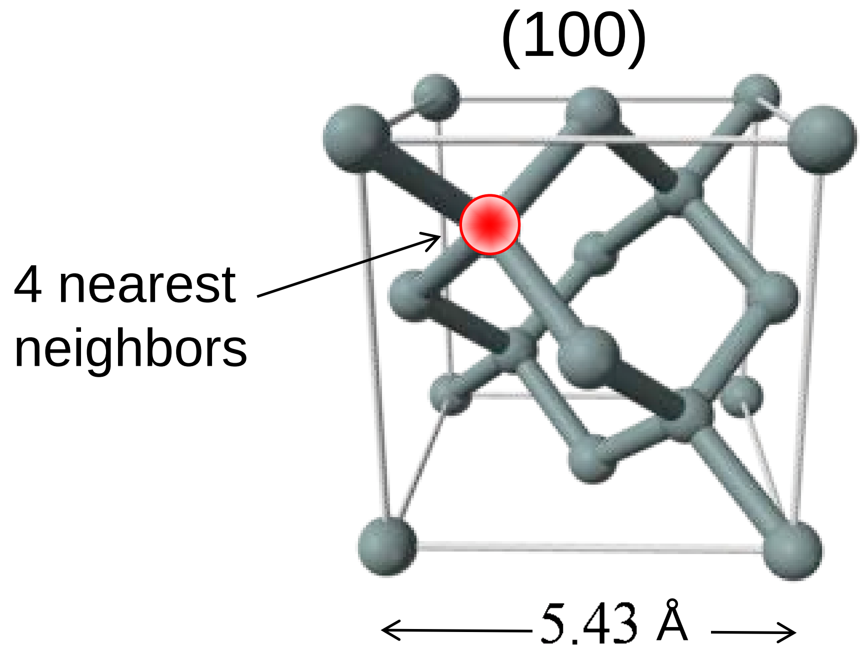
silicon (Si)

insulator

glass (SiO_2)

Example semiconductor: Si

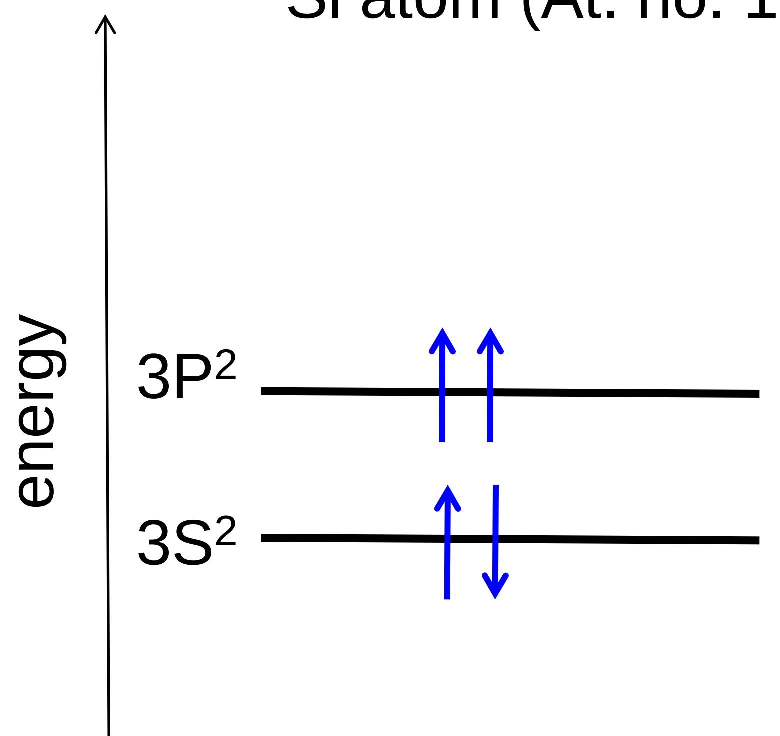




- Si crystallizes in the diamond lattice.
- We specify planes and directions with Miller indices.
- In a solid, energy levels become energy bands.

Silicon energy levels → energy bands

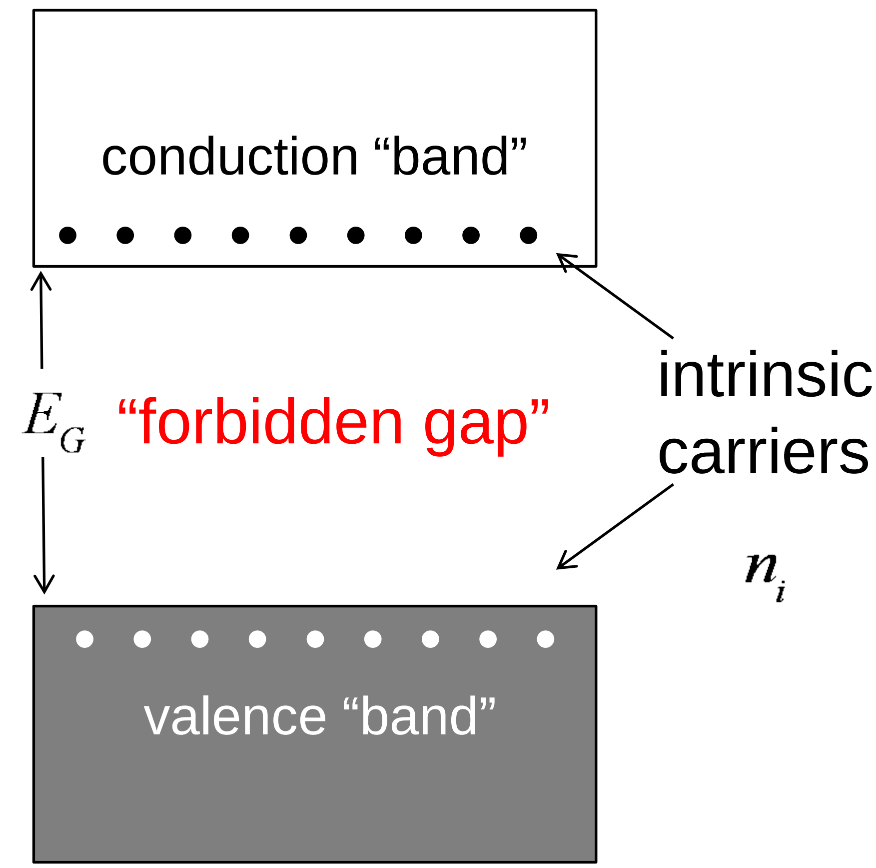
Si atom (At. no. 14)



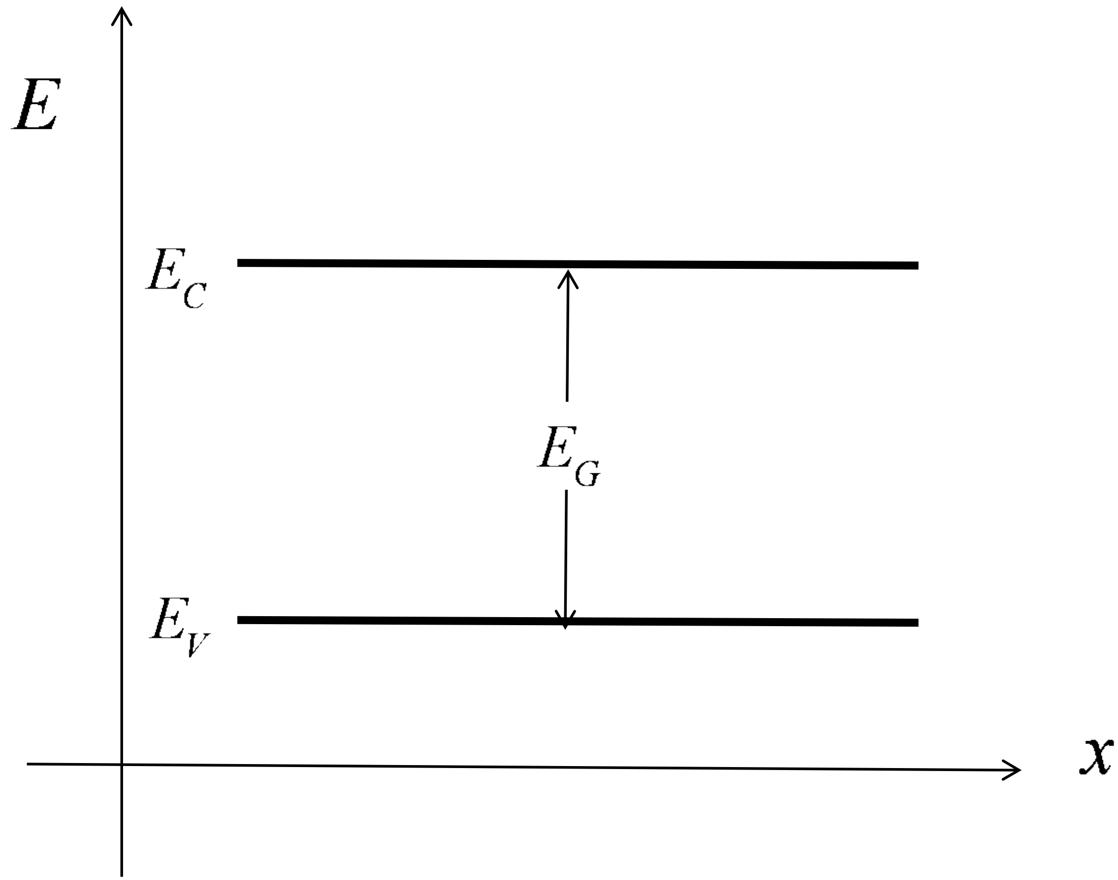
$$T = 300\ \mathrm{K}$$

$$\langle E \rangle = \frac{3}{2} k_B T = 0.039\ \mathrm{eV}$$

Si crystal

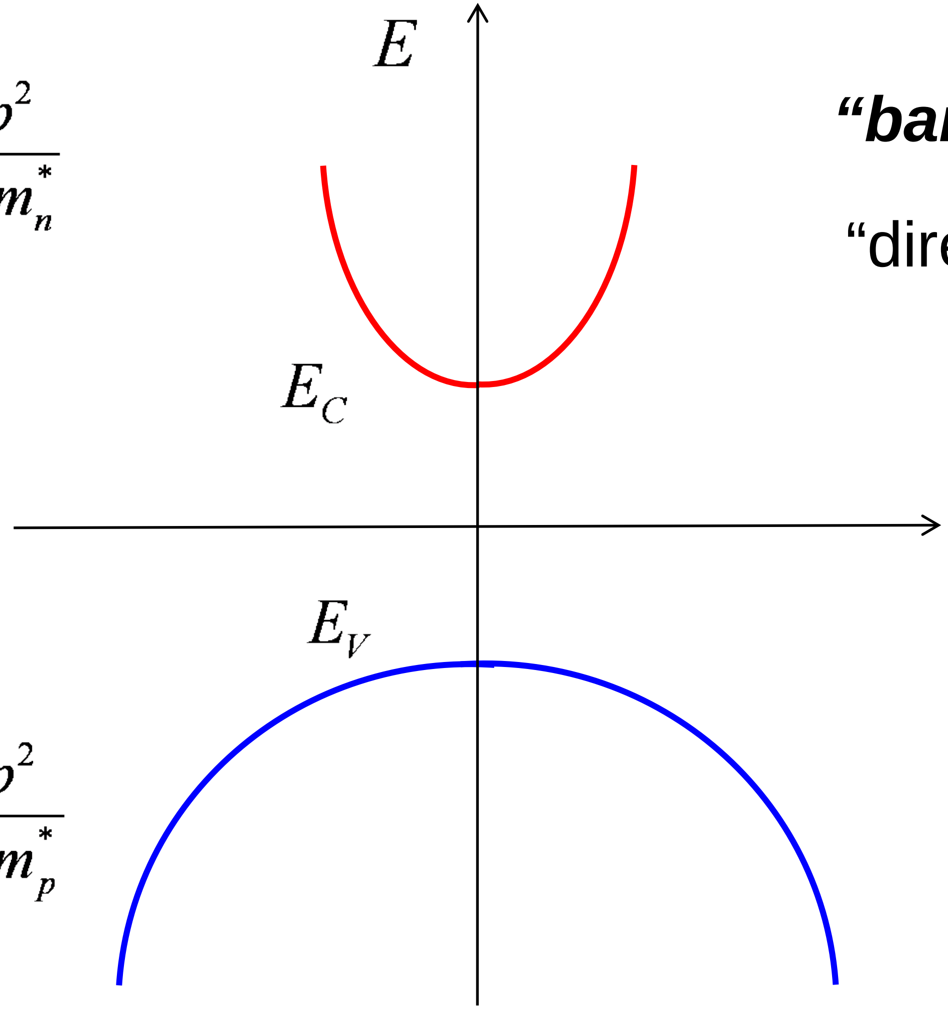


Energy band diagram



Energy vs. momentum: E(k)

$$E = E_C + \frac{p^2}{2m_n^*}$$



$$E = E_V - \frac{p^2}{2m_p^*}$$

"band structure"

"direct bandgap"

$$p = \hbar k$$

$$k = \frac{2\pi}{\lambda}$$

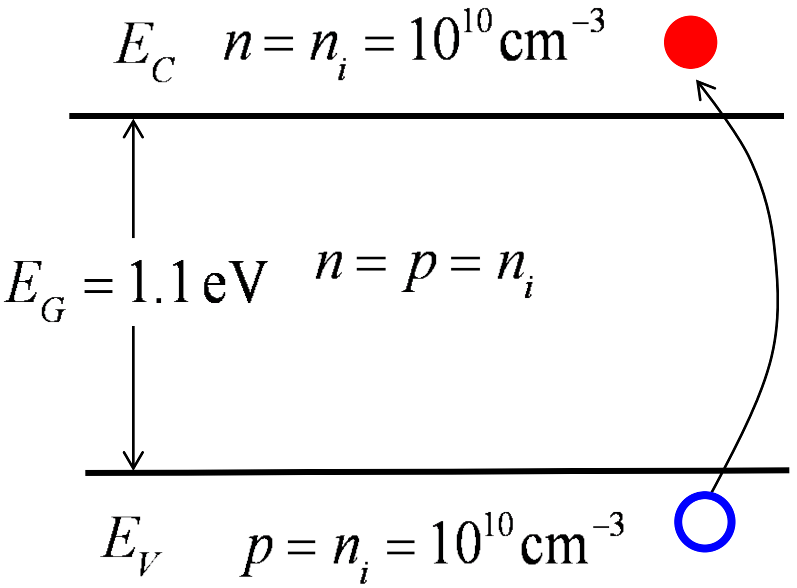
Energy band structure vs. energy band diagram

Band structure is a plot of energy **vs. crystal momentum** (or k).

An energy band diagram is a plot of the bottom of the conduction band and top of the valence band **vs. position.**

Bandgap and intrinsic carrier concentration

Intrinsic Si



$$E_G(\text{Si}) = 1.1\,\text{eV}$$

$$E_G(\text{GaAs}) = 1.4\,\text{eV}$$

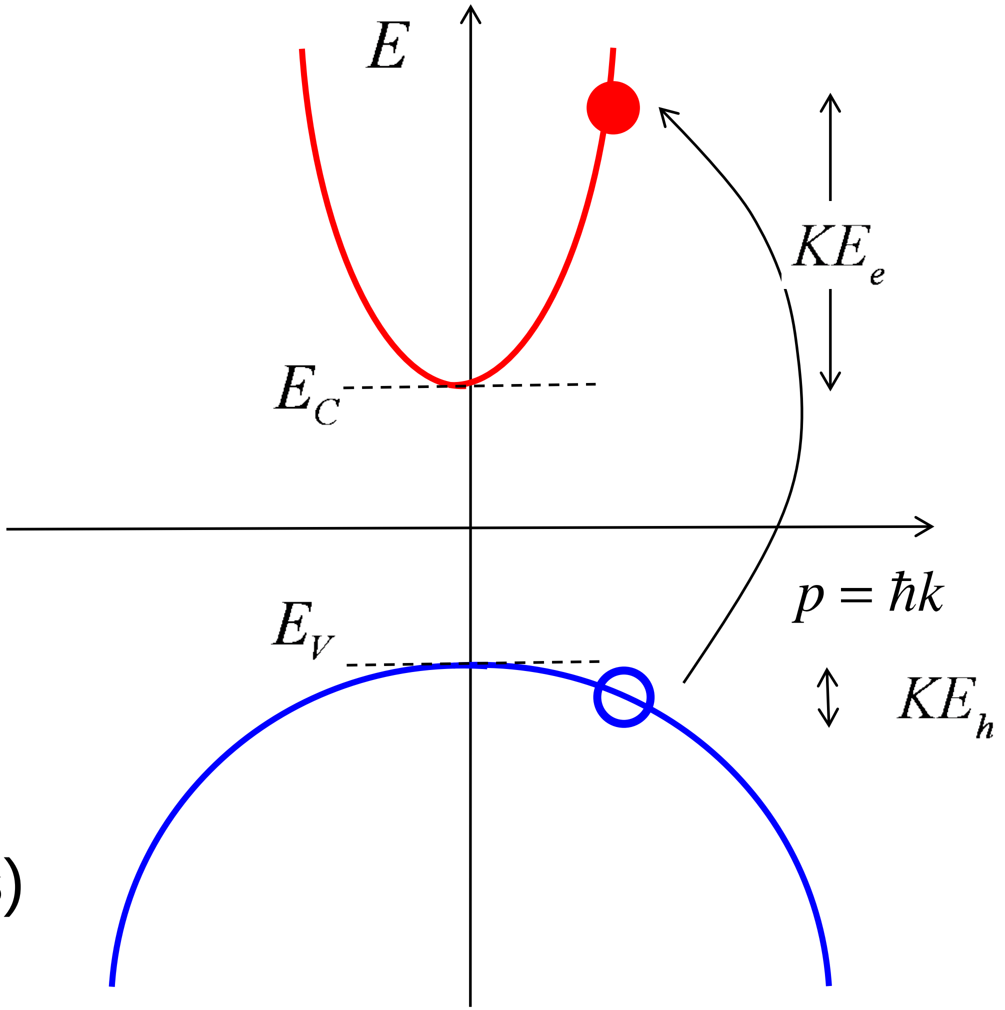
$$E_G(\text{Ge}) = 0.66\,\text{eV}$$

$$n_i(\text{Si}) = 1 \times 10^{10}\ \text{cm}^{-3} \quad (T = 300\ \text{K})$$

$$n_i(\text{GaAs}) = 2 \times 10^{6}\ \text{cm}^{-3} \quad (T = 300\ \text{K})$$

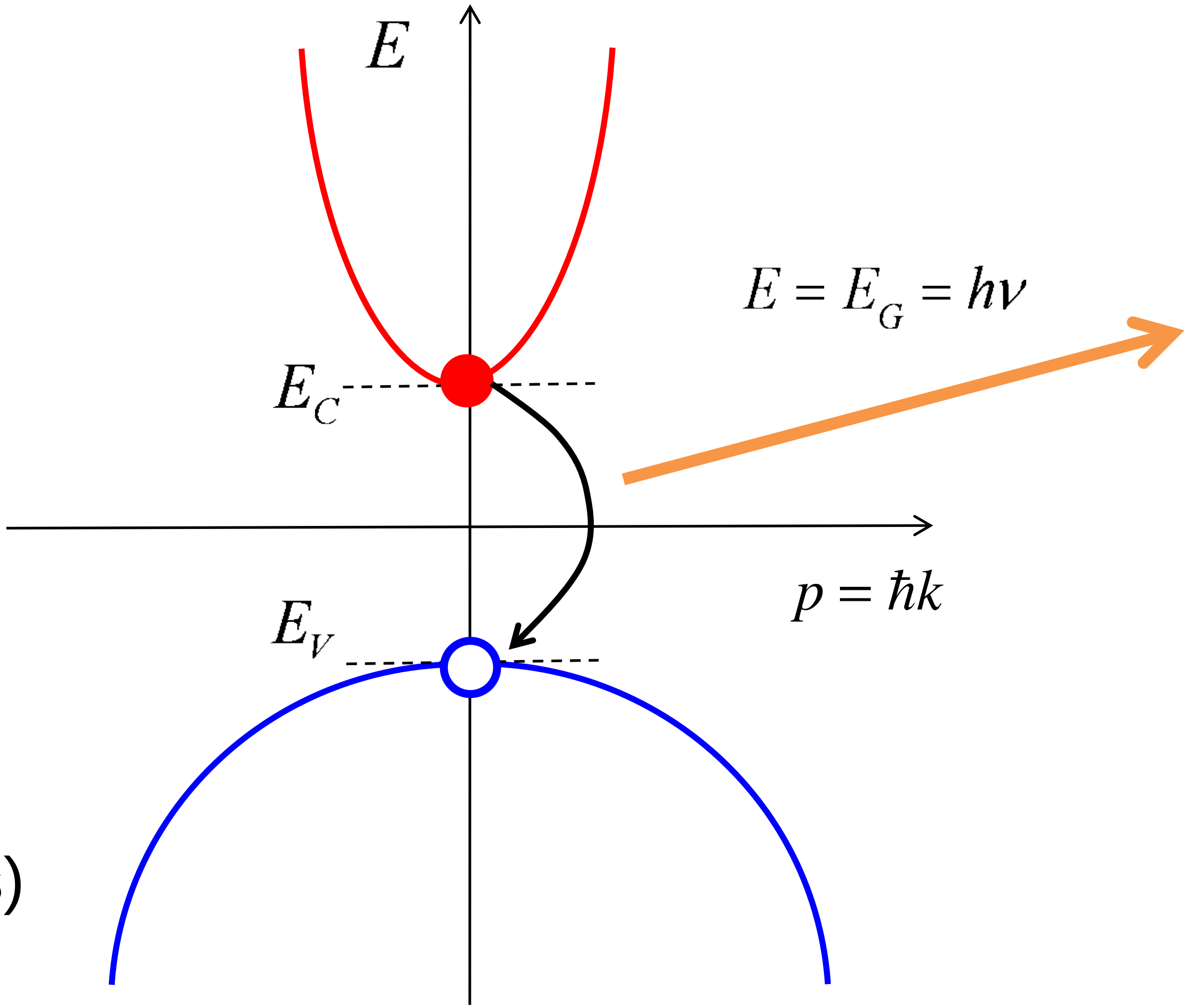
$$n_i(\text{Ge}) = 2 \times 10^{13}\ \text{cm}^{-3} \quad (T = 300\ \text{K})$$

Optical generation: E(k)



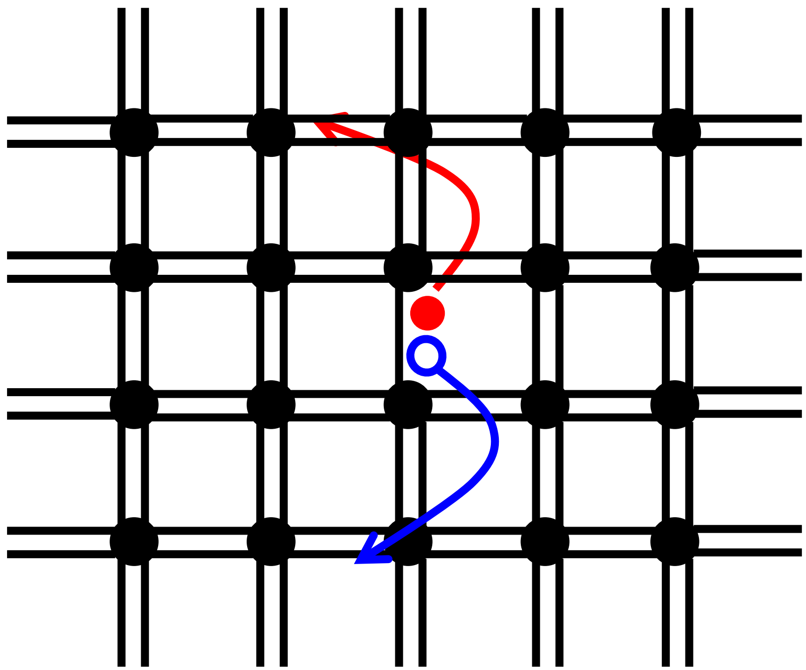
(more complicated for indirect gap semiconductors)

Direct recombination: E(k)



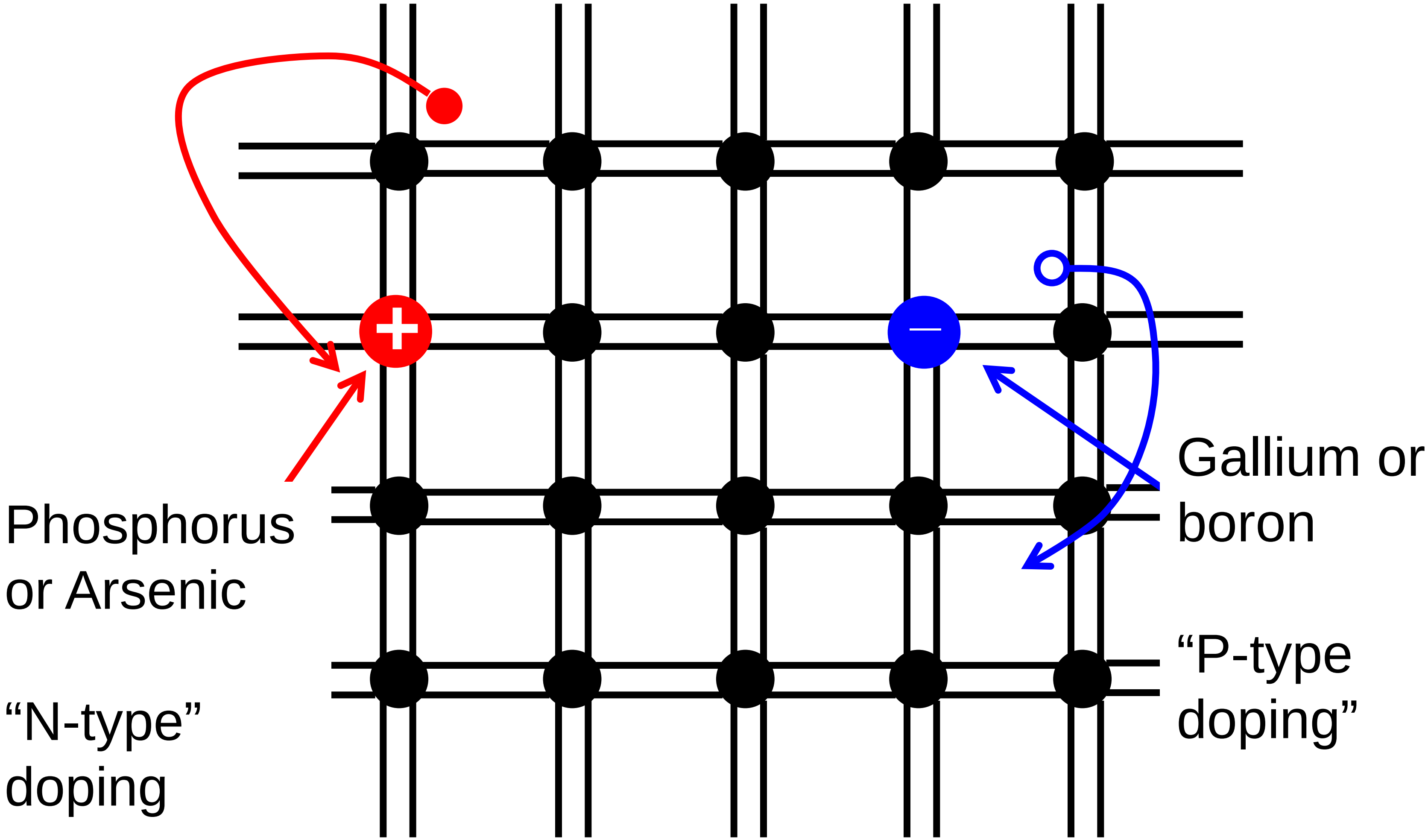
(more complicated for indirect gap semiconductors)

Bonding model view: intrinsic semiconductor

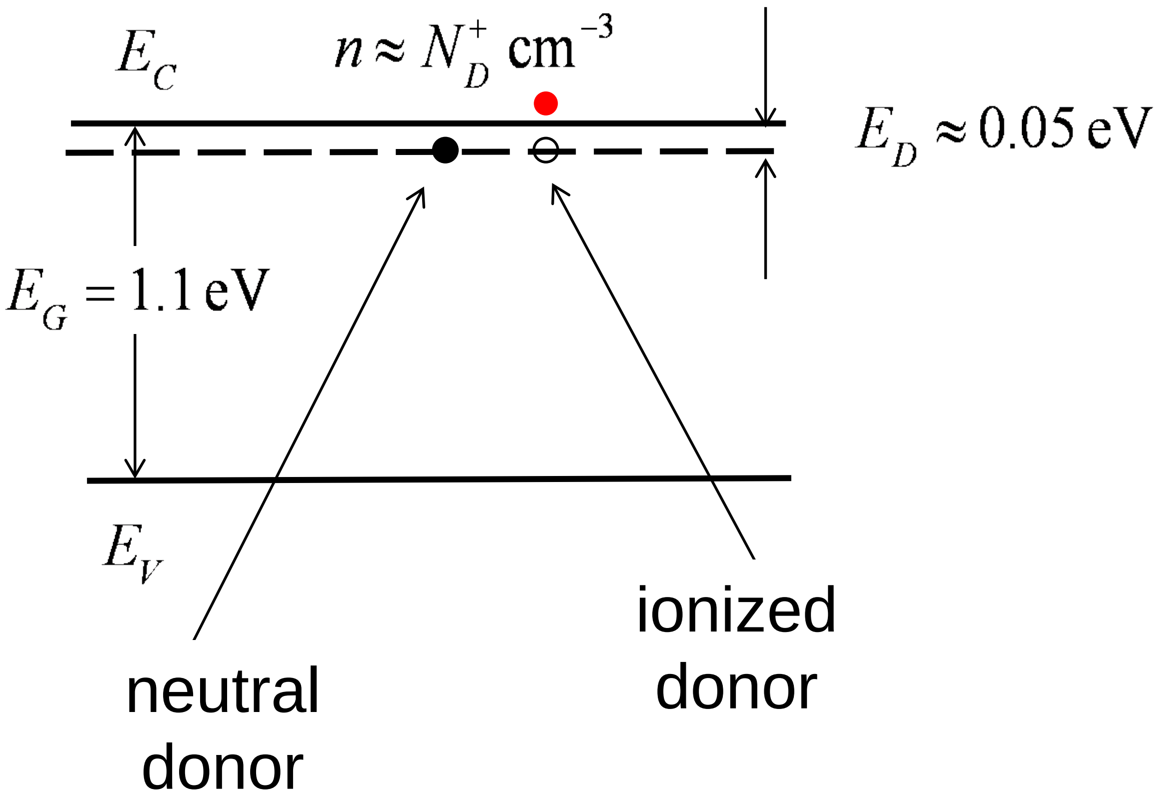


1) Electrons in the conduction band can move
2) Holes in the valence band can move
3) Electrons and holes can recombine

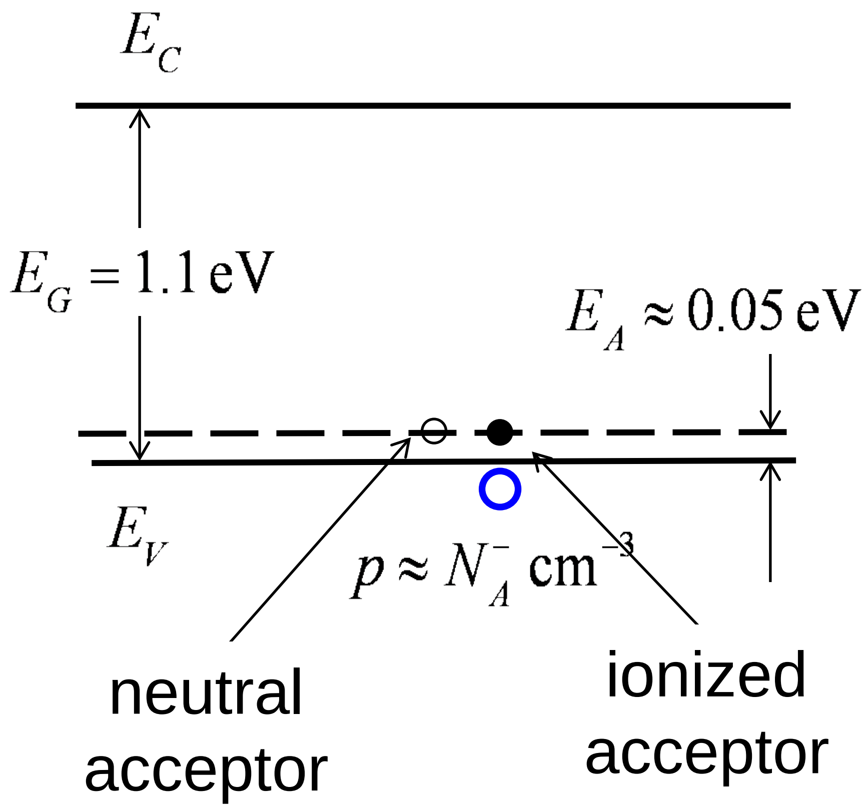
Doping


Phosphorus
or Arsenic
"N-type"
doping
Gallium or
boron
"P-type
doping"

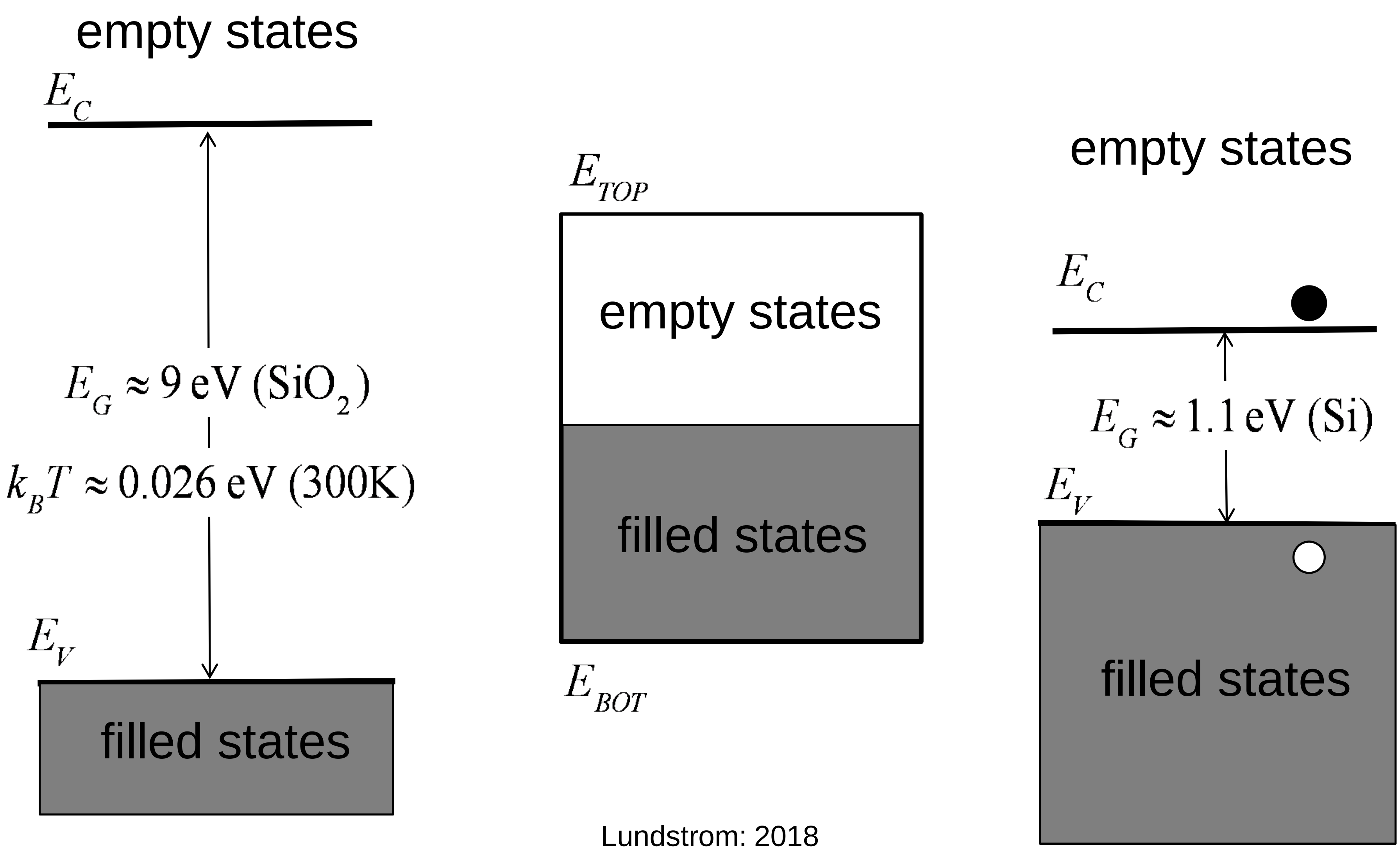
N-type doping: Energy band view



P-type doping: Energy band view



Insulators Metals Semiconductors



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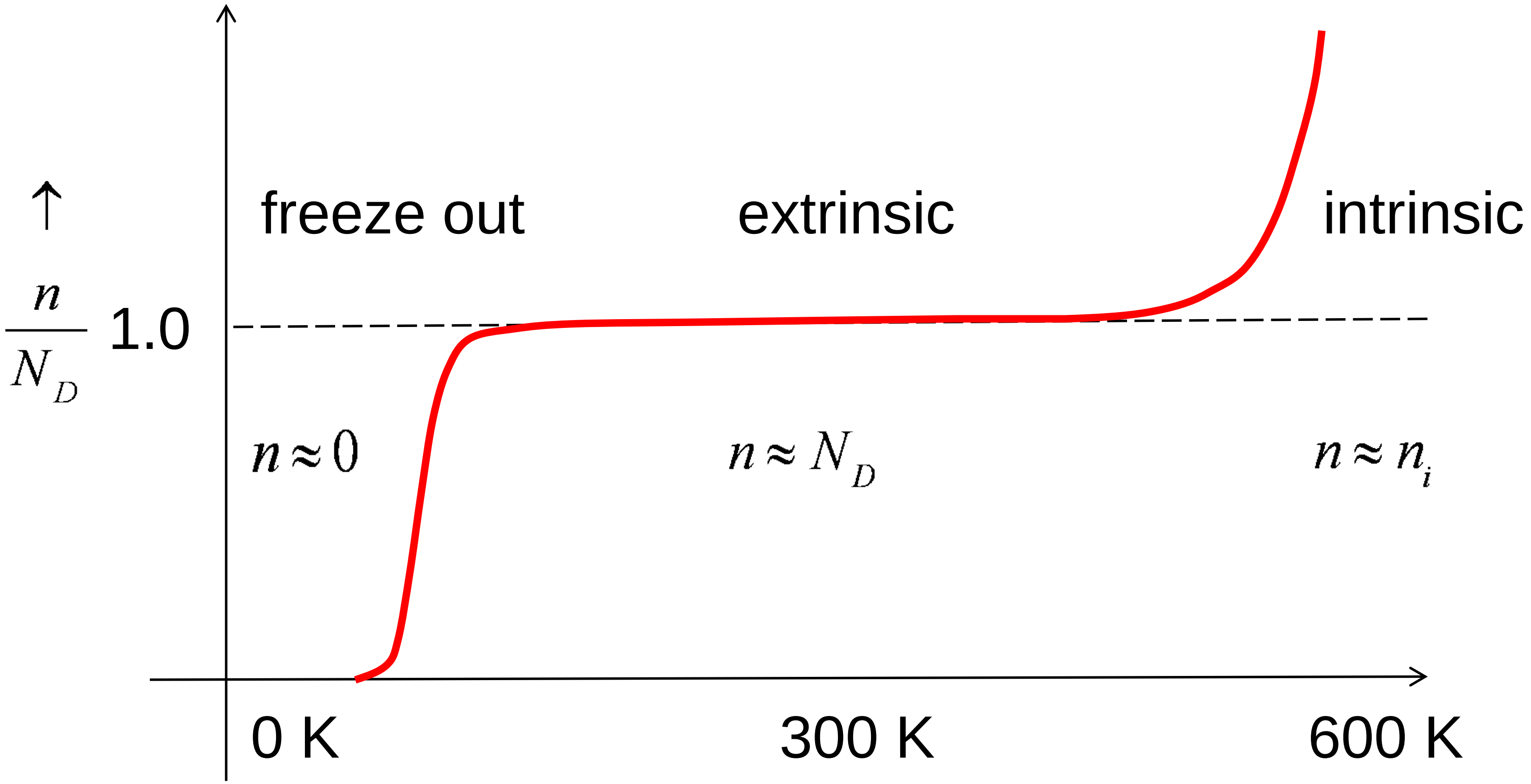
Carrier concentration vs. temperature



Summary

1. Quantization of energy levels

2. Energy bands

3. Electrons and holes

4. Doping

5. Insulators, metals, and semiconductors

Vocabulary

1) Crystalline
2) Amorphous
3) Polycrystalline
4) Bravais lattices
5) Unit cell
6) Primitive unit cell
7) Diamond lattice
8) Zinc blende lattice
9) Miller indices
10) Energy levels
11) Energy bands
12) Forbidden gap (bandgap)
13) Conduction band
14) Valence band
15) Electrons (in the conduction band)
16) Holes (in the valence band)
17) Optical generation
18) Thermal generation
19) Metal
20) Insulator
21) Semiconductor