Semiconductor Fundamentals

Presented to

EE2187 class in Semester 1 2019/20

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Lecture 5

Course information

- Semiconductors Materials - Types of Solids, Space lattice, Atomic Bonding,
- Introduction to quantum theory, Schrodinger wave equation, Electron in free space, Infinite well, and step potentials, Allowed and forbidden bands
- Electrical conduction in solids, Density of states functions, Fermi-Dirac distribution in Equilibrium,
- Valence band and Energy band models of intrinsic and extrinsic Semiconductors. Degenerate and non degenerate doping
- Thermal equilibrium carrier concentration, charge neutrality
- Carrier transport – Mobility, drift, diffusion, Continuity equation.

Reference

Text Book:

1. Physics of Semiconductor Devices, *S. M. Sze*, John Wiley & Sons (1981).
2. Solid State Electronics by *Ben G. Streetman and Sanjay Banerjee*, Prentice Hall International , Inc.
3. Semiconductor Physics and Devices, Donald A. Neamen, Tata Mcgraw-Hill Publishing company Limited.
4. Advanced Semiconductor Fundamentals by Pirret

Reference Book:

1. Fundamentals of Solid-State Electronic Devices, *C. T. Sah*, Allied Publisher and World Scientific, 1991.
2. Complete Guide to Semiconductor Devices, *K. K. Ng*, McGraw Hill, 1995.
3. Solid state physics, Ashcroft & Mermins.
4. Introduction to Solid State Electronics, *E. F. Y. Waug*, North Holland, 1980.

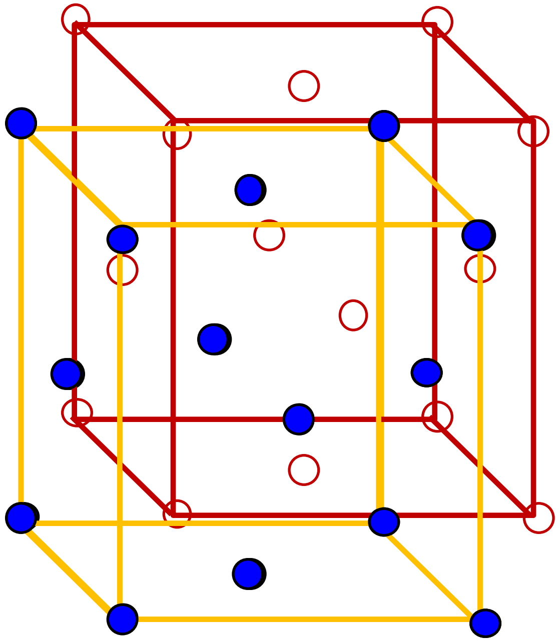
Recap

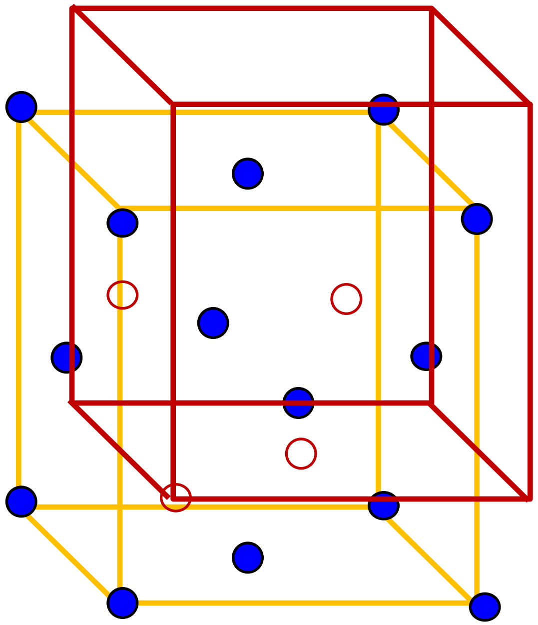
Qualitative Theory (Bond Model)

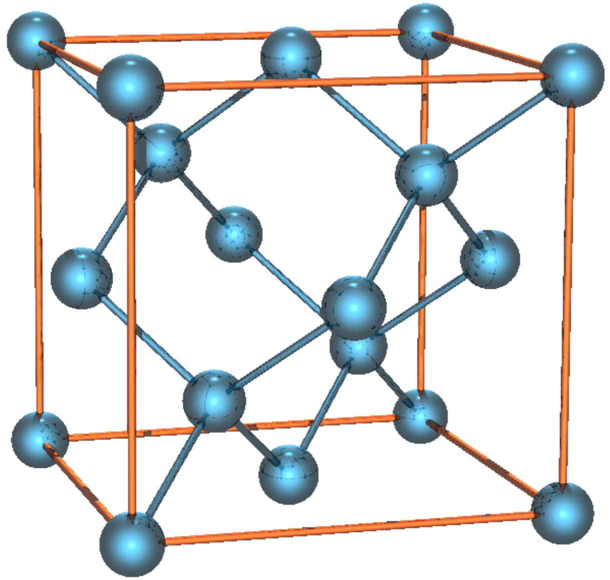
It will give physical insight of

- ✓ Why there is electron and hole i.e how it is generated?
- ✓ why is it that the temperature coefficient of resistivity of semiconductors is negative?
- ✓ Approximate value of carrier concentration
- ✓ why two kind of carrier for current transport?

3D Unit cell of Si



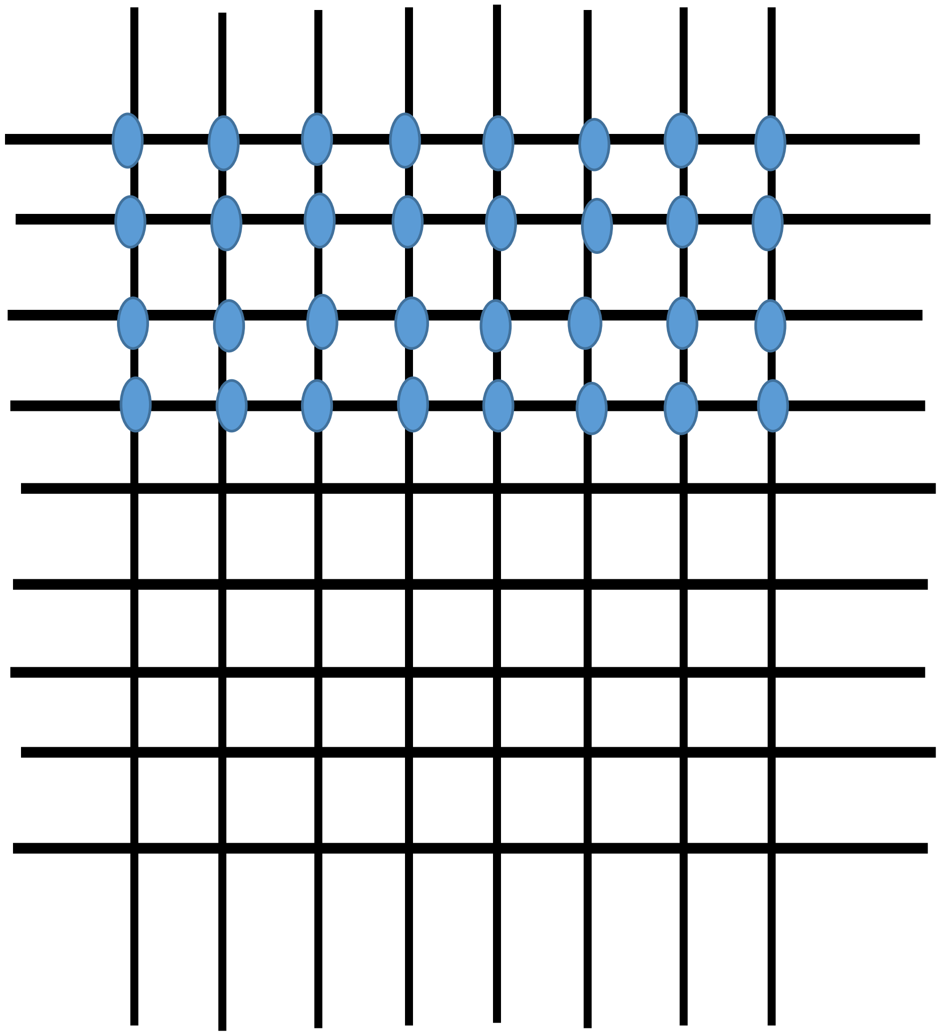




Atomic Concentration: $5*10^{22}$

Lattice constant: 5.43A

Bond Energy =1.12eV

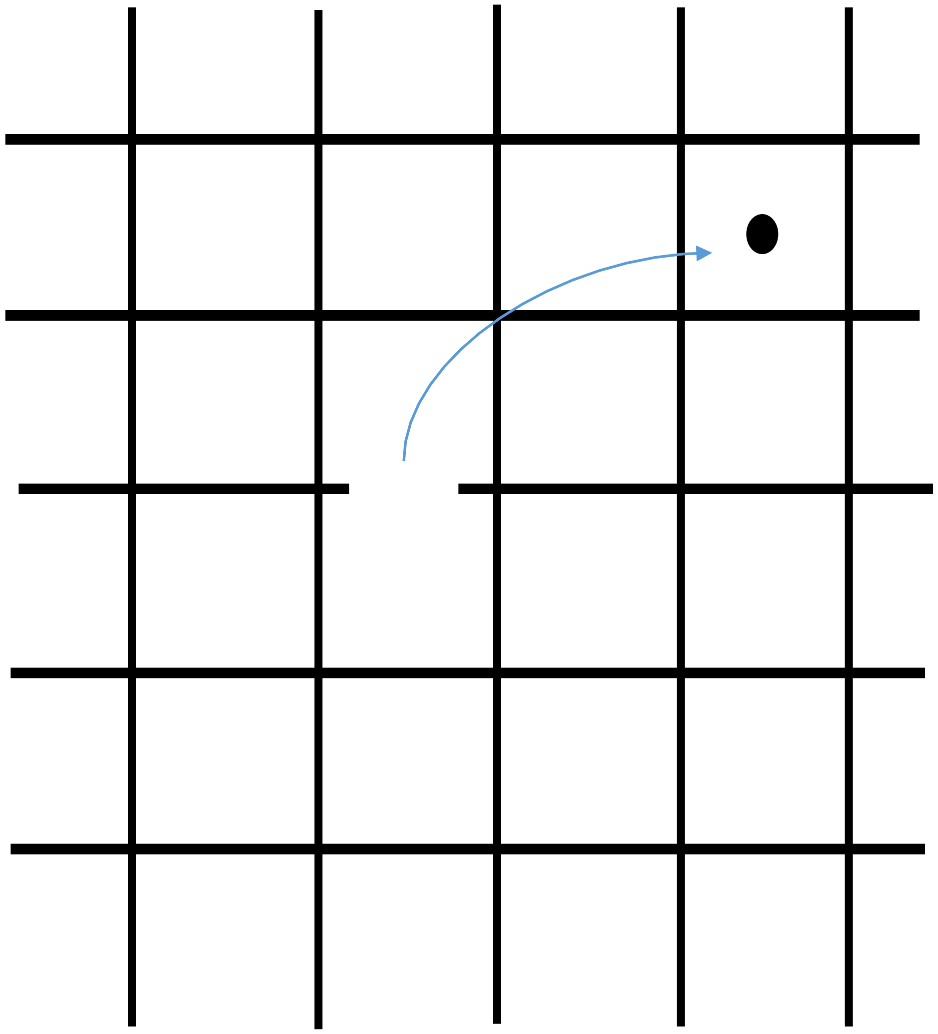


2D representation of 3D crystal

How electron and Holes created?

At T=0K

What happened to lattice point ?



At T>0K

What happened to lattice point ?

Atom vibrate

Acoustic traveling wave generated

Lead Phonons Generation

Dipole Oscillation leads EM traveling wave generated

Lead Photons Generation

At T>0K

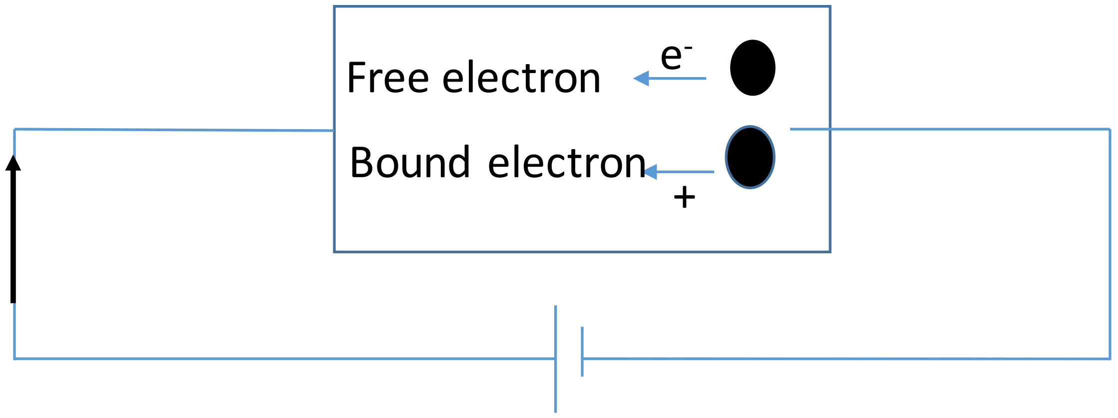
What happened to lattice point ?

Lead Four Particle Generation

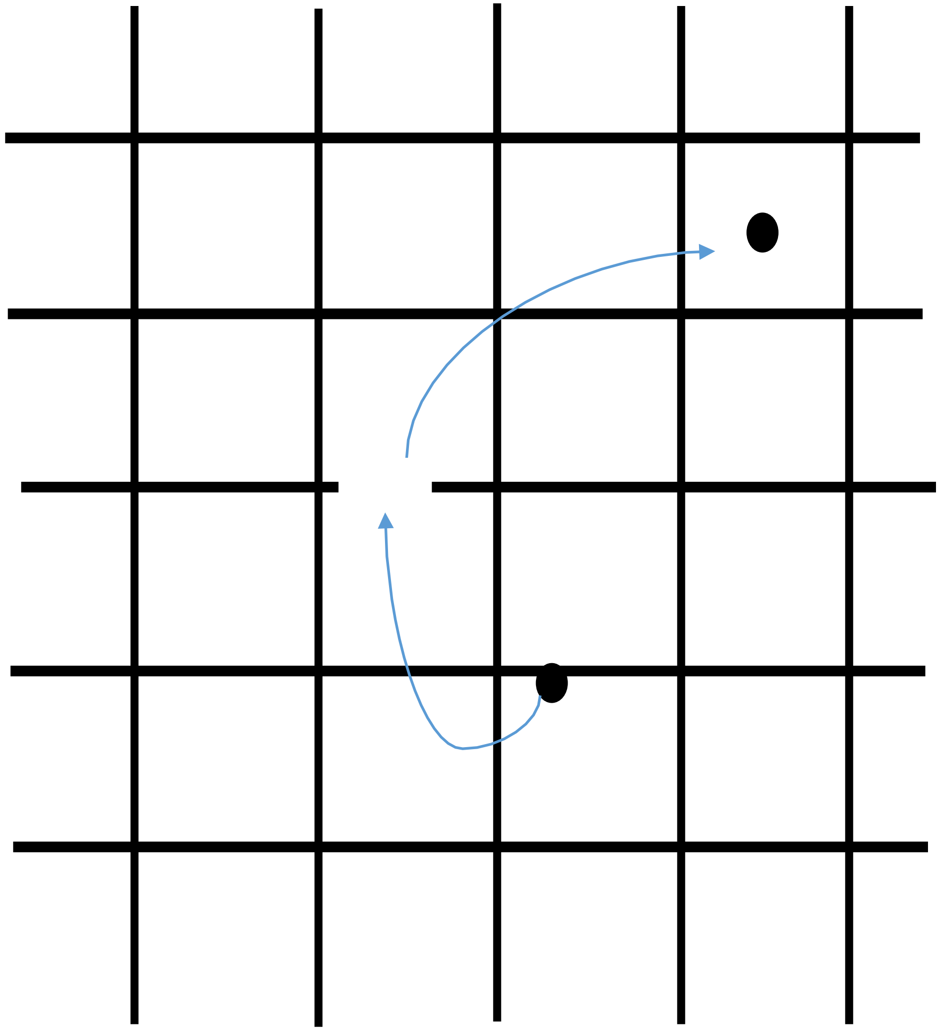
- Phonons
- Photons
- Electrons
- Holes

Concept of Holes

Hole is absence of an electron in a bond between silicon and silicon atoms.



What is bound electron?

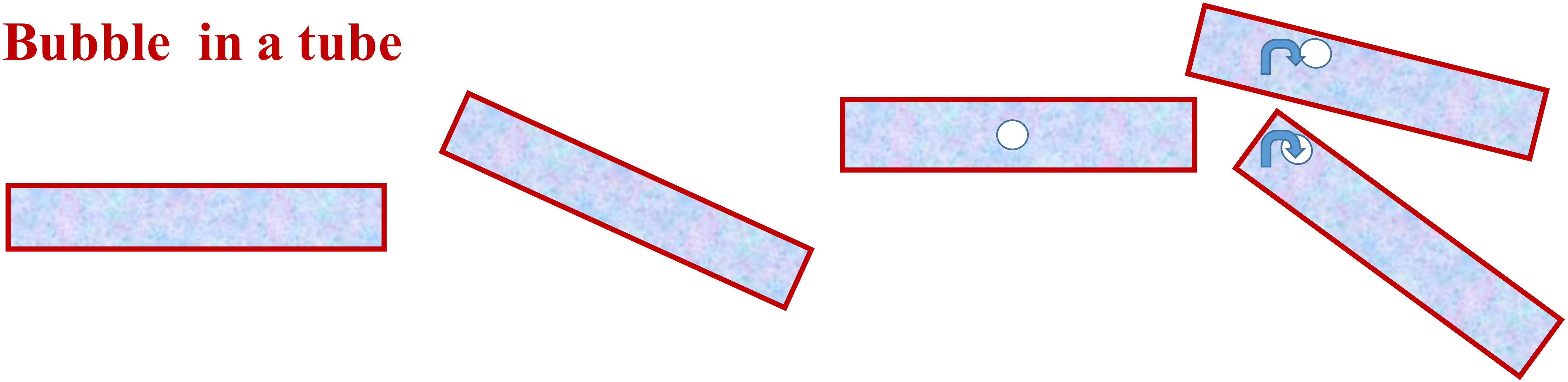


Vacancies which are present can help the bound electrons to move

How this vacancy helping bound electron to move?

Bubble in a tube

Bubble in a tube



Similarly, bound electrons which are present in the silicon crystal tend to move via the vacancies in response to the electric field.

If the vacancies were not there then there is no way they can move

However bound electron movement required energy

However negligible as compared to making a electron free

Vacancy helping bound electron to move hence contribute current

Revisit Concept of Holes

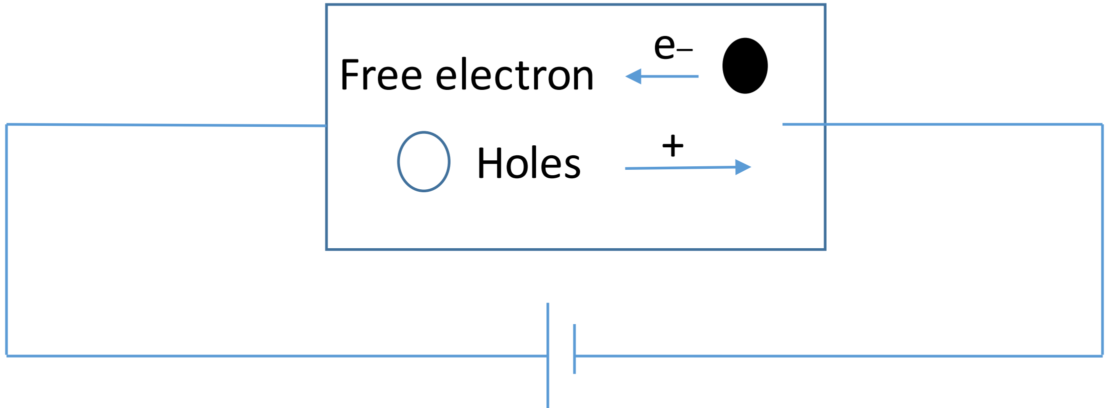
Hole is absence of an electron in a bond between silicon and silicon atoms.

Bound electron is more but vacancy is limited

Our interest is to know rate of bound electron move to get the current

So it is good to focus vacancy motion rater than bound electron, called Holes.

Therefore: Holes is a fictitious particle



Positive charge

Since vacancy is
Moving in direction E

Why carrier concentration increases with T in Si ?

Simplistic model

Let us consider Room temperature is 300K,
So average energy of each particle is= KT=.026eV

So No of electron required to removed the electron from atoms =1.1/.026~42

Let probability of particle having interaction with Si atom is p
So the probability of the 42 particle coming on the same atoms p^{42}

Let us calculate the probability

We know ni(300K)~10^{10} and No. of Si atom in /cm3~10^{22}
$P^{42}=10^{10}/10^{22}$~????,

Why carrier concentration increases with T in Si ?

Simplistic model

Now, let us consider, higher temperature 400K,
So average energy of each particle is= KT=.026eVx400/300=

So No of electron required to removed the electron from atoms =1.1*3/.026x4~ 32
So the probability of the 32 particle coming on the same atoms p^{32}

So probability of 32 electron coming together is more likely than 42

We we can observe that carrier concentration will be higher at higher temperature

Let us formulate

No of e-h pair created at temperature T

Bond strength

$$n_i = Np^{E/kT}$$

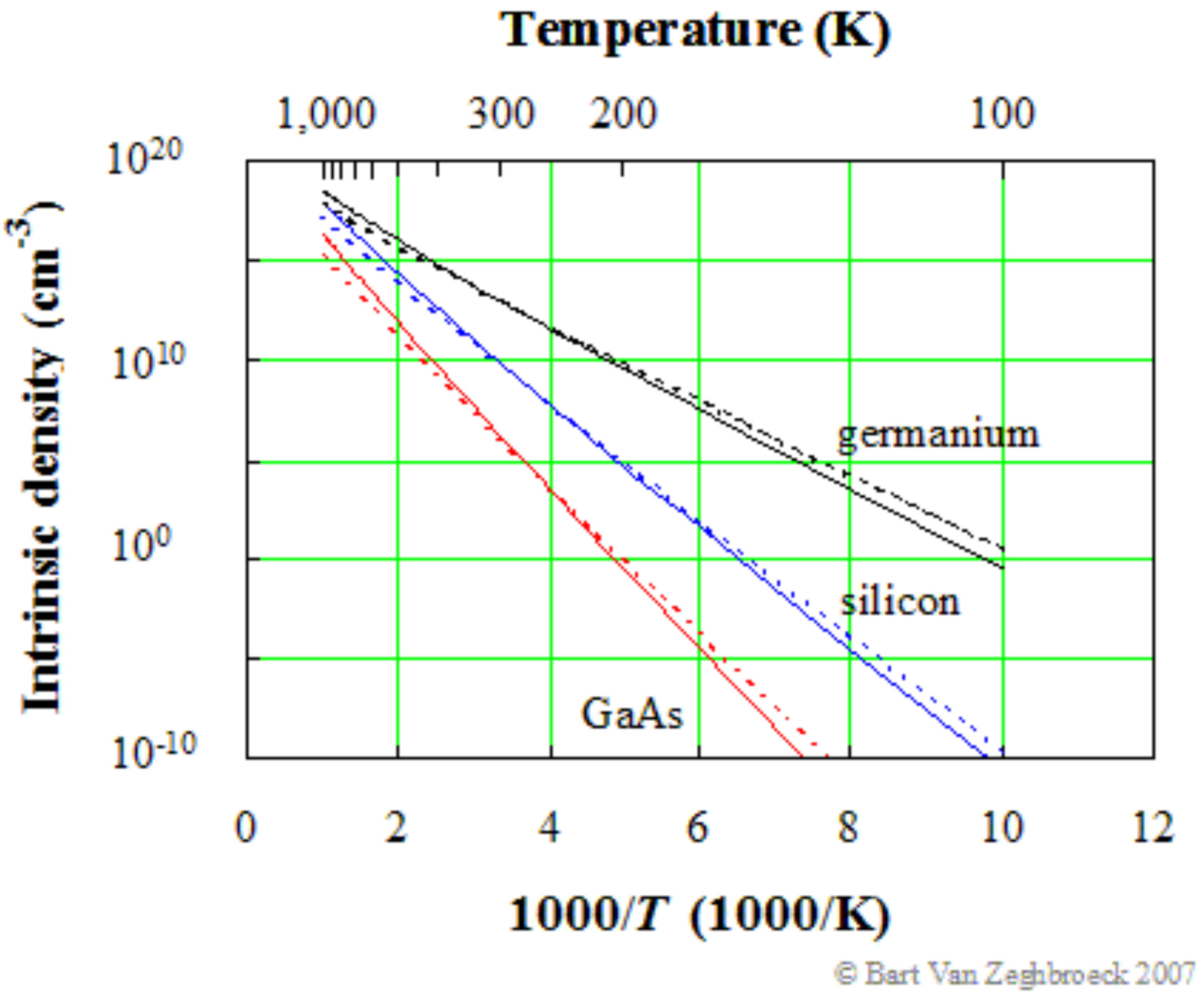
$$n_i = N\left(\frac{1}{p}\right)^{-E/kT}$$

Atomic concentration

Probability of particle having interaction with Si atom
Which is <1

>1

Intrinsic carrier density with temperature a w.r.t. different materials



$$n_i = N\left(\frac{1}{p}\right)^{-E/kT}$$

$$Log n_i \propto -E/kT Log\left(\frac{1}{p}\right)$$

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