JAIPUR ENGINEERING COLLEGE AND RESEARCH CENTRE

- Year & Sem – Ist Year , Ist Sem
- Subject – Engineering Physics
- Chapter–Material Science and Semiconductor Physics (Part- A)
- Department- Applied Science (Physics)

VISION

To become a renowned institute of outcome based learning and work towards academic, professional, cultural and social enrichment of the lives of individuals and communities.

MISSION

- Focus on valuation of learning outcomes and motivate students to inculcate research aptitude by project based learning.
- Identify based on informed perception of Indian, regional and global needs, the areas of focus and provide platform to gain knowledge and solutions.
- Offer opportunities for interaction between academia and industry.
- Develop human potential to its fullest extent so that intellectually capable and imaginatively gifted leaders can emerge in a range of professions.

Syllabus & Course Outcomes

- **Syllabus :- Material Science & Semiconductor Physics:** Bonding in solids: covalent and metallic bonding, Energy bands in solids: Classification of solids as Insulators, Semiconductors and Conductors, Intrinsic and extrinsic semiconductors, Fermi dirac distribution function and Fermi energy, Conductivity in semiconductors, Hall Effect: Theory, Hall Coefficient and applications.
- **Course Outcomes:** Students will be able to describe key concepts of bonding and its types, formation of energy bands in solids, Fermi energy and Fermi distribution function to understand the Physics of semiconductors and materials.

CONTENTS

- Bonding in solids and types of Bonding
- Formation of Energy bands in solids and their types
- Fermi Energy and Fermi distribution function
- Problems
- Lecture contents with a blend of NPTEL contents and other platforms
- References/ Bibliography

Lecture Plan

S. No	Topics	Lectures required	Lect. No.
1	Introduction to bonding of solids: covalent & metallic bonding.	1	1
2	Formation of energy bands in Solids , Classification of Solids as insulators, semiconductors and conductors on the basis of energy bands.	1	2
3	Fermi energy and Fermi distribution function	1	3
4	Problems	1	4

Bonding

Bonding : A solid is composed of a millions of atoms, molecules and the ions which are closely packed together through force of attraction. These attractive forces which holds the constituent particles together is called a bond and this phenomenon is called bonding and the types of bonding depends on the electronic structure of the atom.

Types of bonding

- Bonding is mainly of two types :
- Covalent bonding
- Metallic bonding

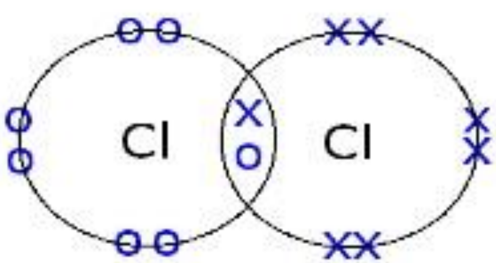
COVALENT BONDING

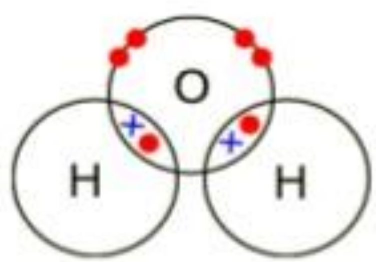
A covalent bond is formed, when two or more electrons of an atom, in its outermost energy level, are shared by other atoms. e.g.-Chlorine molecule.

In this bonding a stable arrangement is achieved by sharing of electrons rather than transfer of electrons.

Sometimes a covalent bond is also formed when two atoms of different non-metals share one or more pair of electrons in their outermost energy level.

e.g.- Water molecule





PROPERTIES OF COVALENT SOLIDS

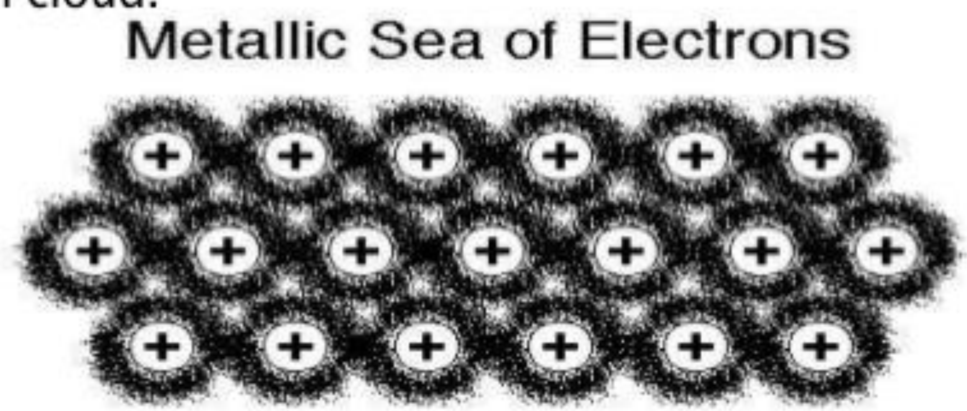
- Covalent compounds are bad conductors of electricity.
- Covalent compounds are having low melting and boiling points.
- Insoluble- in water
- Soluble- in organic solvents like Benzene

METALLIC BONDING

It has been observed that in a metal atoms, the electrons in their outermost energy levels are loosely held by their nucleii.

Thus a metal may be considered as a cluster of positive ions surrounded by a large number of free electrons, forming electron cloud.

e.g.– a

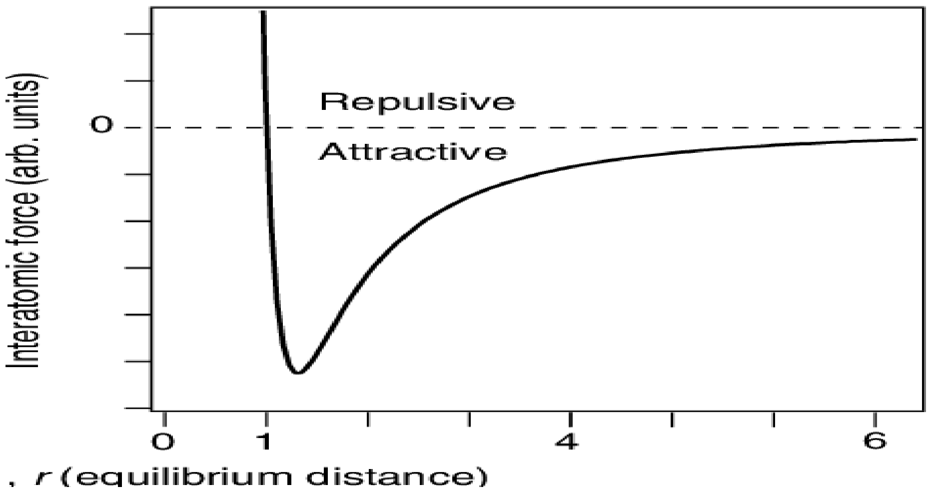


PROPERTIES OF METALLIC SOLIDS

- High thermal and electrical conductivity
- Low melting and boiling point temperature
- Have a bright lustre
- Metallic solids are malleable and ductile

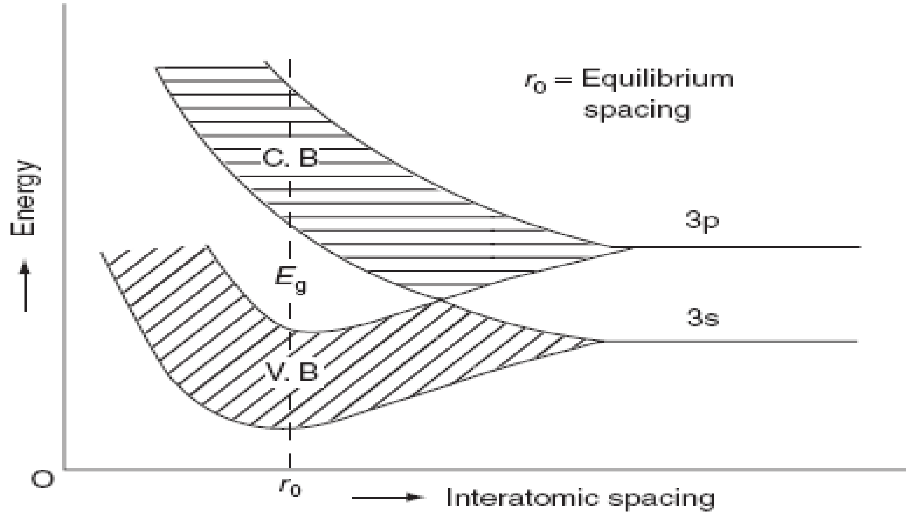
Origin and nature of forces between atoms or the ions of a solid crystal

- When the atoms or ions comes closer to each other, the interatomic separation reduces and initially the attractive forces plays a dominant role and increases with the inverse square of atomic distance which further reduces the atomic distance.
- When the interatomic distance reduces more than a limit ,the repulsive forces come into existence and sharply increases with the reduction in atomic distances.
- Thus the attractive and repulsive forces nullify each other at a particular interatomic separation and the system hold the position of equilibrium with lowest potential energy, i.e. bonding energy. In this way atomic or primary bonds are formed.



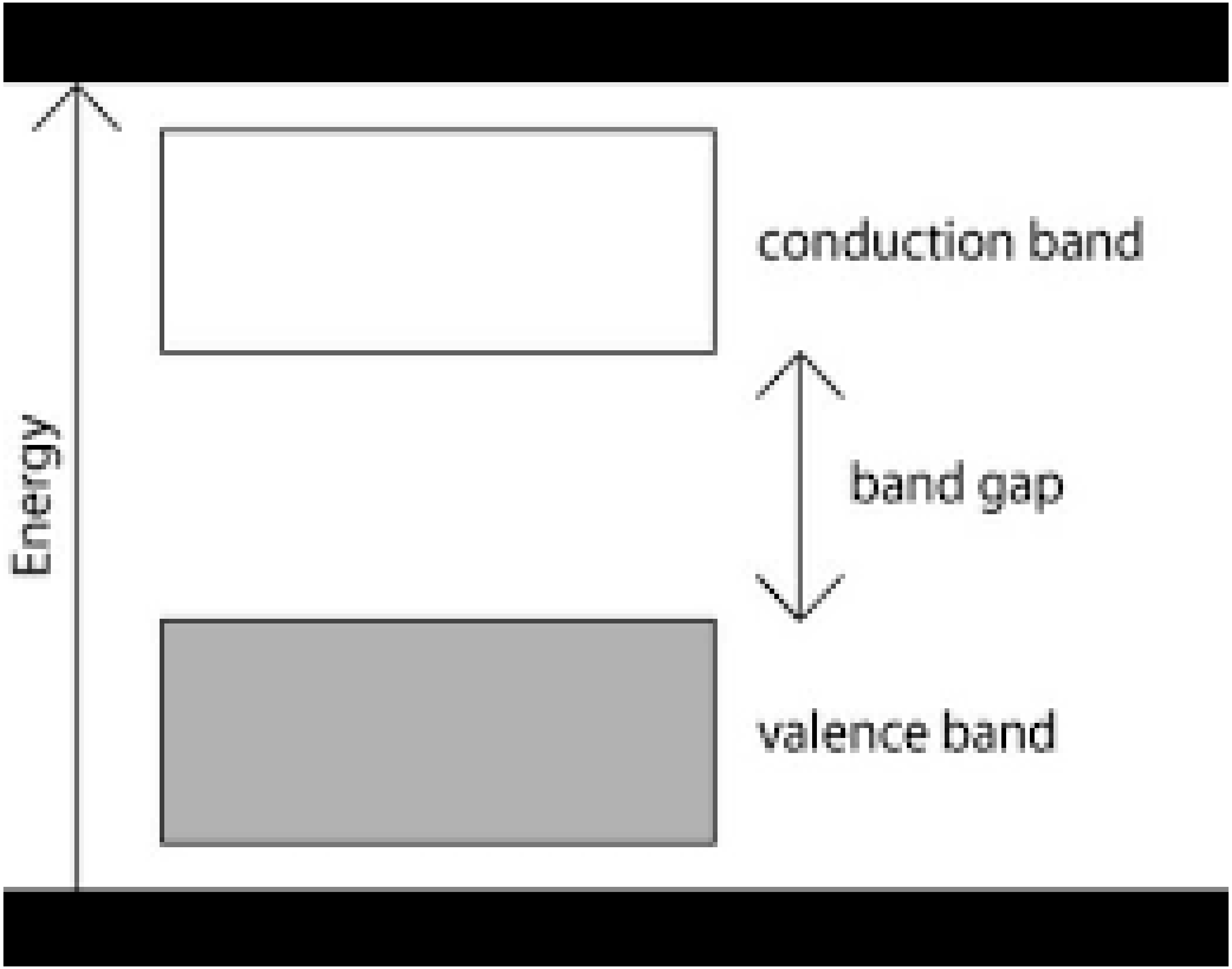
Energy bands in Solids

Each orbit has a fixed amount of energy associated with it. The electron moving in a particular orbit of the atom possess the energy of that orbit. Larger the orbit greater is the energy. In case of a single isolated atom each electron has a definite amount of energy, however an atom in a solid is greatly influenced by neighboring atoms. The electron in any orbit of atom can have a range of energies rather than a single value. The range of energies possessed by electrons in a solid is known as energy band.



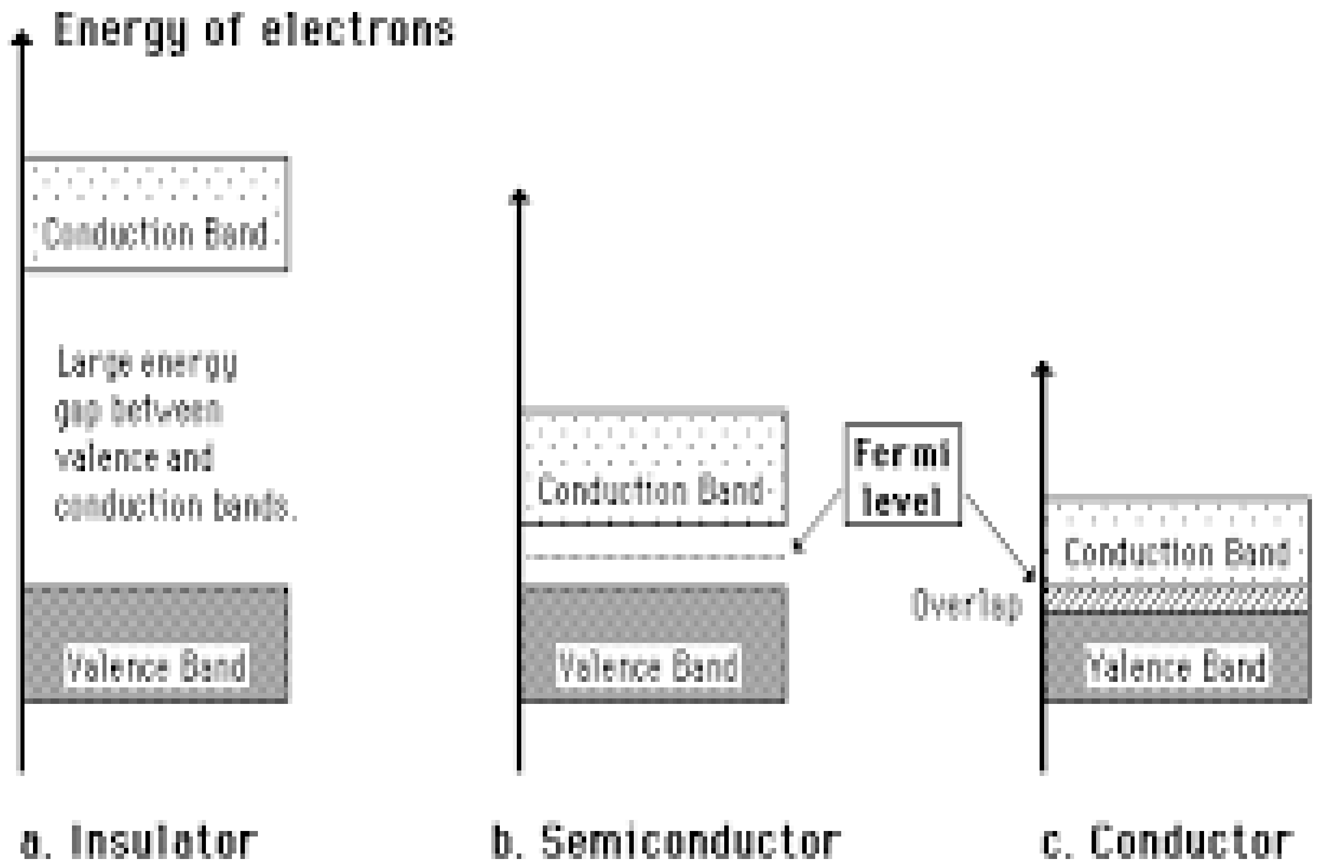
Types of energy bands in solids

- **Valence band:** The range of energies possessed by valence electrons in solids is called a valence bond. It is the highest electron filled energy band.
- **Forbidden energy gap :** The minimum amount of energy required to jump the electrons from valence band to conduction band. No electron is found in this gap.
- **Conduction band:** The range of energies possessed by free electrons in solids is called conduction band. In the conduction band the electrons are almost free.


Energy
conduction band
band gap
valence band

Classification of solids on the basis of energy band gap

S.No	Insulators	Semiconductors	Conductors
1	Conduction band is empty	Conduction band is empty	Conduction band is filled
2	Ideally no charge carriers	Electrons and holes are charge carriers	Only electrons are charge carriers
3	Conductivity does not change	Conductivity increases with the increase in temperature	Conductivity decreases with the increase in temperature
4	Resistivity decreases' with the increase in temperature	Resistivity decreases with the increase in temperature	Resistivity increases with the increase in temperature
5	eg. Wood, plastic	eg. Silicon and Germanium	eg. All metals


Energy of electrons
Conduction Band
Large energy gap between valence and conduction bands.
Valence Band
Conduction Band
Fermi level
Valence Band
Conduction Band
Overlap
Valence Band
a. Insulator
b. Semiconductor
c. Conductor

Fermi energy and Fermi distribution Function

- **Some basic concepts:-**

- Fermi level :- This is the term used to describe the top of the collection of electron energy levels at absolute zero temperature.

- Fermi energy:-This is the maximum energy that an electron can have in a conductor at 0K. It is given by

$$E_F = \frac{1}{2} m v_F^2$$

where v_F is the velocity of electron at Fermi level.

Fermi-Dirac distribution and the Fermi-level

Density of states tells us how many states exist at a given energy E. The Fermi function $f(E)$ specifies how many of the existing states at the energy E will be filled with electrons. The function $f(E)$ specifies, under equilibrium conditions, the probability that an available state at an energy E will be occupied by an electron. It is a probability distribution function.

$$f(E) = \frac{1}{1 + e^{(E-E_F)/kT}} \quad (2.7)$$

E_F = Fermi energy or Fermi level

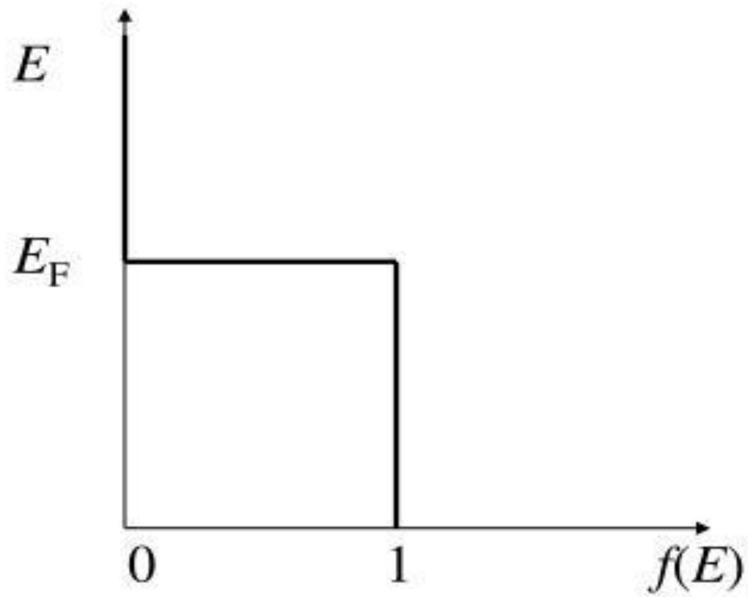
k = Boltzmann constant = 1.38×10^{-23} J/K = 8.6×10^{-5} eV/K

T = absolute temperature in K

Fermi-Dirac distribution: **Consider $T \rightarrow 0$ K**

For $E > E_F$:
$$f(E > E_F) = \frac{1}{1+\exp(+\infty)} = 0$$

For $E < E_F$:
$$f(E < E_F) = \frac{1}{1+\exp(-\infty)} = 1$$



Fermi-Dirac distribution: **Consider $T > 0$ K**

If $E = E_F$ then $f(E_F) = ½$

If $E \geq E_F + 3kT$ then $\exp\left(\frac{E - E_F}{kT}\right) >> 1$

Thus the following approximation is valid: $f(E) = \exp\left(\frac{-(E - E_F)}{kT}\right)$

i.e., most states at energies $3kT$ above E_F are empty.

If $E \leq E_F - 3kT$ then $\exp\left(\frac{E - E_F}{kT}\right) << 1$

Thus the following approximation is valid: $f(E) = 1 - \exp\left(\frac{E - E_F}{kT}\right)$

So, $1 - f(E)$ = Probability that a state is empty, decays to zero.

So, most states will be filled.

kT (at 300 K) = 0.025eV, E_g(Si) = 1.1eV, so $3kT$ is very small in comparison.

Temperature dependence of Fermi-Dirac distribution

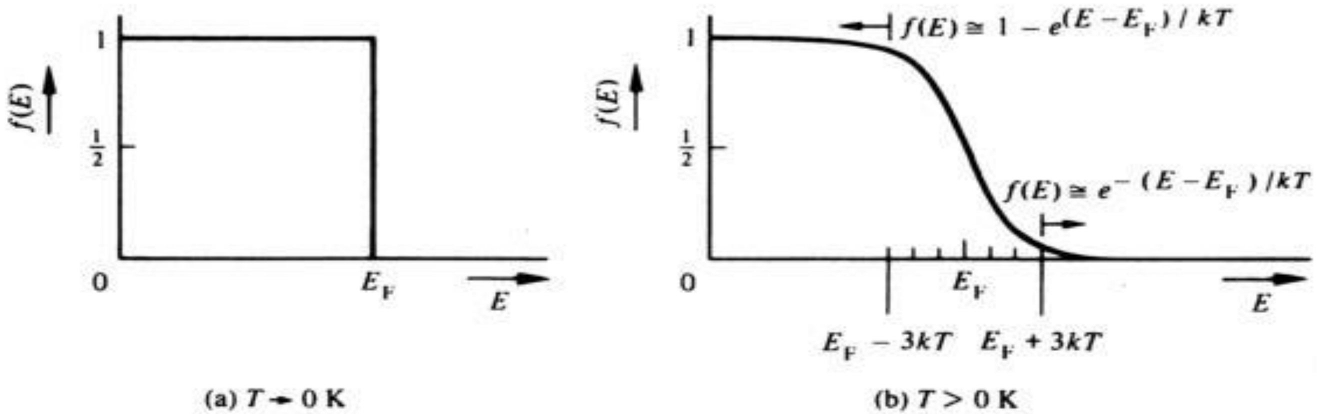
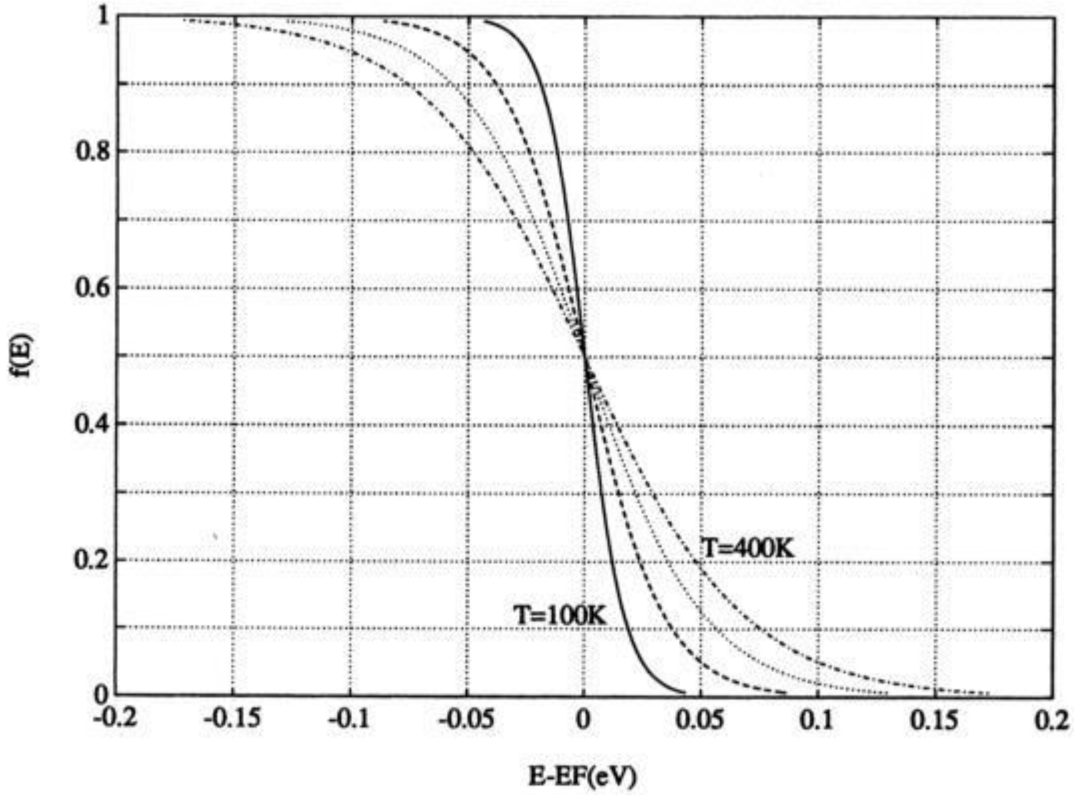


Figure 2.15



1
0.8
0.6
0.4
0.2
0
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
f(E)
E-EF(eV)
T=400K
T=100K

Problems

- Find the resistance of an intrinsic Ge rod 1 cm lon , 1mm wide and 1mm thick at 300 K. For Ge $n_i = 2.5x10^{19}$ /m^3. Mobility of electrons = .39 m^2/VS, Mobility of Holes = .19 m^2/VS.
- The electron and hole motilities in In-Sb semiconductor are 6 and 0.2 $m^2V^{-1}s^{-1}$ respectively. At room temperature, the resistivity of In-Sb semiconductor is $2x10^{-4}$ ohm meter. Assuming that material is intrinsic, determine its intrinsic carrier density at room temperature.
- The electron mobility in a pure semiconductor is 50 $m^2v^{-1}s^{-1}$ at 4.2 K. What is its mobility at 300 K? The conductivity of semiconductor at 20^0 C is 250 mhos/m and at 100^0 C is 1100 mhos/m. What is its band gap E_g ?

LECTURE CONTENTS WITH A BLEND OF NPTEL CONTENTS AND OTHER PLATFORMS

- https://nptel.ac.in/courses/115/105/115105122/
  (Video lecture by Prof. Arghya Taraphder)
- https://youtu.be/03j4ZvQCKWY
  (Video lecture by Dr. Amitava Dasgupta)
- https://youtu.be/rwCsBE_06FU
  (Video lecture by Prof. V.K. Tripathi)
- https://www.youtube.com/watch?v=knVD1AfiozA
  (Video lecture by Dr. Prathap Haridoss))

REFERENCES/BIBLOGRAPHY

- Material Science by Smith, MC Graw Hill , New Delhi
- Handbook of Electronics by G.K. Mithal
- Integrated electronics by Jacob Millman and Hailkias ,Mc Graw Hill Ltd
- Engineering Physics by Dr. Y.C.Bhatt , Ashirwad Publications
- Engineering Electronics by John D Ryder, MC Graw Hill , New Delhi
- Solid State Physics by S. O. Pillai, New Age International Publisher

THANK YOU !

(Part-B to be continued in next PPT)