ELECTRONIC I

Lecture 1

Introduction to semiconductor

By

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SOLID-STATE ELECTRONIC MATERIALS

- Electronic materials generally can be divided into three categories: **insulators, conductors,** and **semiconductors.**
- The primary parameter used to distinguish among these materials is the **resistivity** ρ, with units of $\Omega \cdot$cm.

Electrical Classification of Solid Materials

MATERIALS	RESISTIVITY ($\Omega \cdot$ cm)
Insulators	$10^5 < \rho$
Semiconductors	$10^{-3} < \rho < 10^5$
Conductors	$\rho < 10^{-3}$

Semiconductors materials

- **Elemental semiconductors** are formed from a single type of atom (column IV of the periodic table of elements),

		IIIA	IVA	VA	VIA
		5 10.811 **B** Boron	6 12.01115 **C** Carbon	7 14.0067 **N** Nitrogen	8 15.9994 **O** Oxygen
		13 26.9815 **Al** Aluminum	14 28.086 **Si** Silicon	15 30.9738 **P** Phosphorus	16 32.064 **S** Sulfur
IIB					
30 65.37 **Zn** Zinc	31 69.72 **Ga** Gallium	32 72.59 **Ge** Germanium	33 74.922 **As** Arsenic	34 78.96 **Se** Selenium	
48 112.40 **Cd** Cadmium	49 114.82 **In** Indium	50 118.69 **Sn** Tin	51 121.75 **Sb** Antimony	52 127.60 **Te** Tellurium	
80 200.59 **Hg** Mercury	81 204.37 **Tl** Thallium	82 207.19 **Pb** Lead	83 208.980 **Bi** Bismuth	84 (210) **Po** Polonium	

Portion of the Periodic Table, Including the Most Important Semiconductor Elements (shaded)

Semiconductors materials

- **compound semiconductors** can be formed from combinations of elements from columns III and V or columns II and VI. These later materials are often referred to as III–V (3–5) or II–VI (2–6) compound semiconductors.
- Table presents some of the most useful possibilities.
- There are also ternary materials such as mercury cadmium telluride, gallium aluminum arsenide, gallium indium arsenide, and gallium indium phosphide

Semiconductor Materials

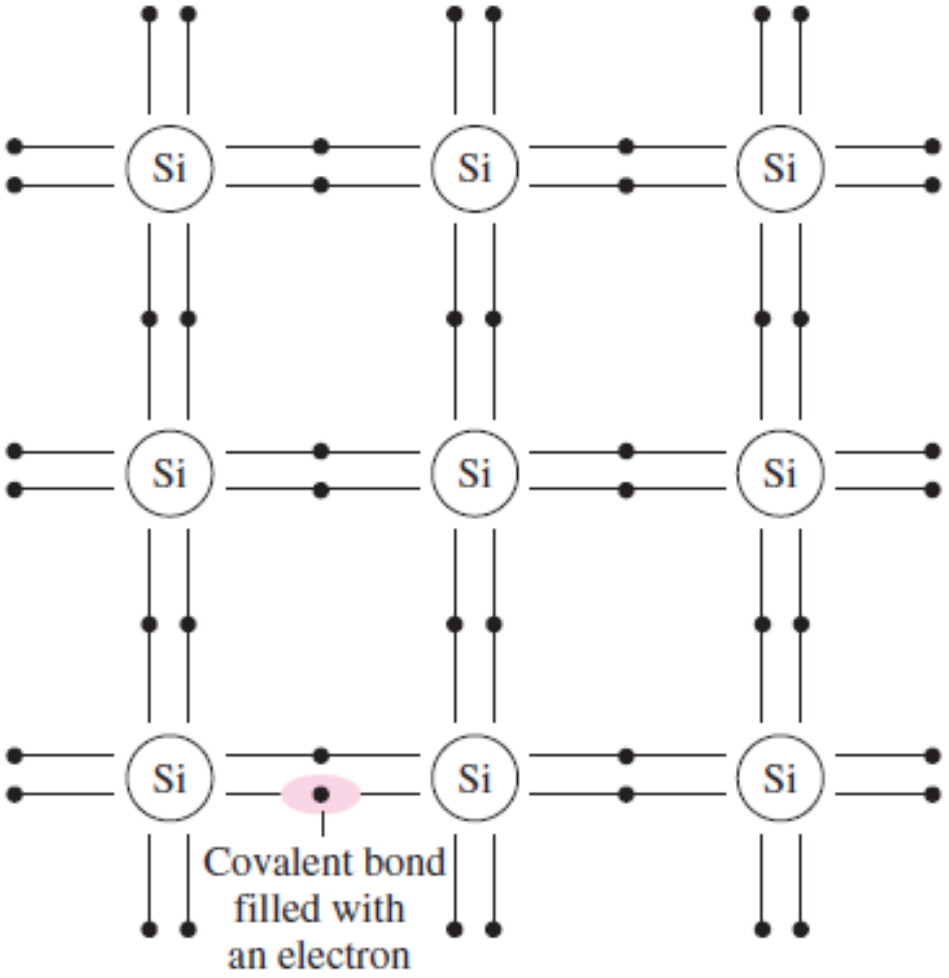
SEMICONDUCTOR	BANDGAP ENERGY E_G (eV)
Carbon (diamond)	5.47
Silicon	1.12
Germanium	0.66
Tin	0.082
Gallium arsenide	1.42
Gallium nitride	3.49
Indium phosphide	1.35
Boron nitride	7.50
Silicon carbide	3.26
Silicon germanium	1.10
Cadmium selenide	1.70

Semiconductors materials

- Historically, germanium was one of the first semiconductors to be used. However, it was rapidly supplanted by silicon, which today is the most important semiconductor material. Silicon has a wider bandgap energy,1 enabling it to be used in higher-temperature applications than germanium, and oxidation forms a stable insulating oxide on silicon, giving silicon significant processing advantages over germanium during fabrication of ICs.
- The compound semiconductor materials gallium arsenide (GaAs) and indium phosphide (InP) are the most important material for optoelectronic applications, including light-emitting diodes (LEDs), lasers, and photodetectors.

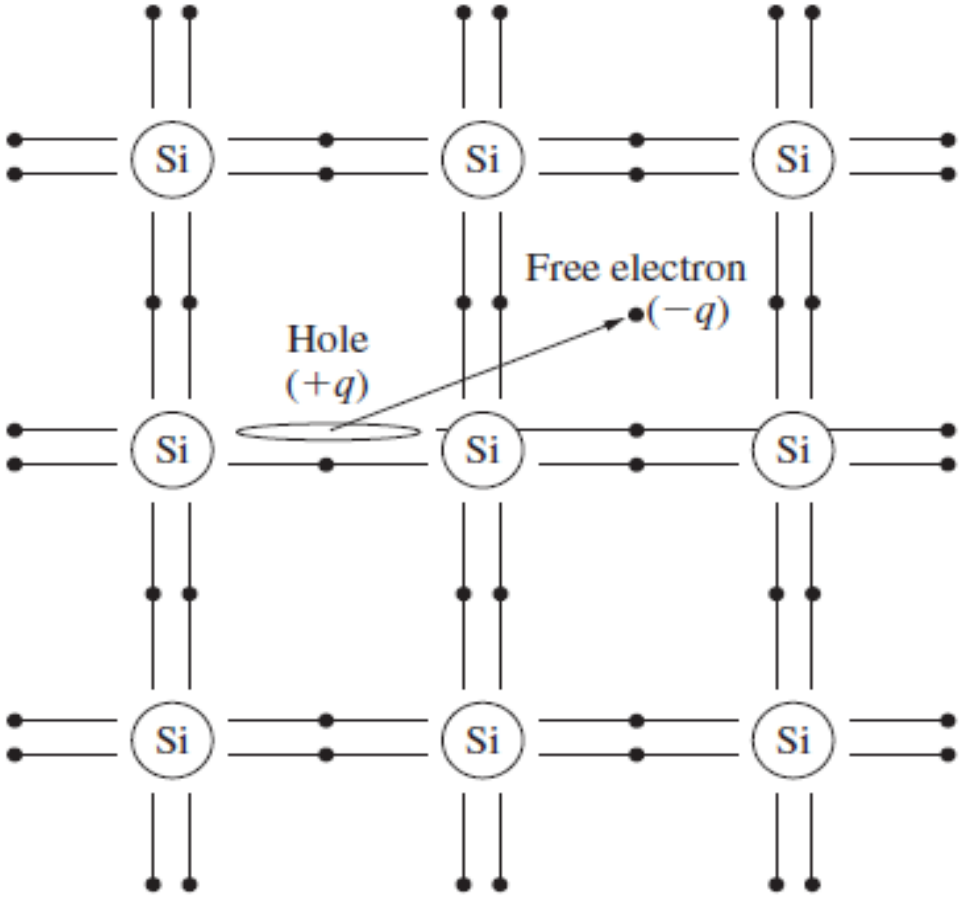
COVALEN

- At temperatures approachin absolute zero, all th electrons reside in th covalent bonds share between the atoms in th array, with no electrons fre for conduction.



COVALENT BOND MODEL

- The outer shells of the silicon atoms are full, and the material behaves as an insulator. As the temperature increases, thermal energy is added to the crystal and some bonds break, freeing a small number of electrons for conduction, a



COVALENT BOND MODEL

- The density of these free electrons is equal to the **intrinsic carrier density *ni*** (cm^{-3}), which is determined by material properties and temperature:

$$n_i^2 = BT^3 \exp\left(-\frac{E_G}{kT}\right) \qquad \text{cm}^{-6}$$

- Where, E_G =semiconductor bandgap energy in eV (electron volts)

  k =Boltzmann's constant, 8.62×10^{-5} eV/K

  T =absolute temperature, K

  B =material-dependent parameter, 1.08×10^{31} $K^{-3} \cdot cm^{-6}$ for Si

COVALENT BOND MODEL

- **Bandgap energy *EG*** is the minimum energy needed to break a covalent bond in the semiconductor crystal, thus freeing electrons for conduction.
- The *density of conduction (or free) electrons* is represented by the symbol ***n*** (electrons/cm3), and for **intrinsic material** *n* = *ni* . The term *intrinsic* refers to the generic properties of pure material. Although *ni* is an intrinsic property of each semiconductor, it is extremely temperature-dependent for all materials.

COVALENT BOND MODEL

- EXAMPLE **:** Calculate the theoretical value of *ni* in silicon at room temperature.

$$n_i^2 = 1.08 \times 10^{31}\ (\mathrm{K}^{-3} \cdot \mathrm{cm}^{-6})(300\ \mathrm{K})^3 \exp\left[\frac{-1.12\ \mathrm{eV}}{(8.62 \times 10^{-5}\ \mathrm{eV/K})(300\ \mathrm{K})}\right]$$

$$n_i^2 = 4.52 \times 10^{19}/\mathrm{cm}^6 \qquad \text{or} \qquad n_i = 6.73 \times 10^9/\mathrm{cm}^3$$

- Exercise: **Calculate the value of *ni* in germanium at a temperature of 320 K. where B=** 2.31×10^{30}

COVALENT BOND MODEL

- A second charge carrier is actually formed when the covalent bond is broken. As an electron, which has charge $-q$ equal to -1.602×10^{-19} C, moves away from the covalent bond, it leaves behind a **vacancy** in the bond structure in the vicinity of its parent silicon atom.
- The vacancy is left with an effective charge of $+q$. An electron from an adjacent bond can fill this vacancy, creating a new vacancy in another position. This process allows the vacancy to move through the crystal.
- The moving vacancy behaves just as a particle with charge $+q$ and is called a **hole. Hole density** is represented by the symbol ***p*** (holes/cm^3).

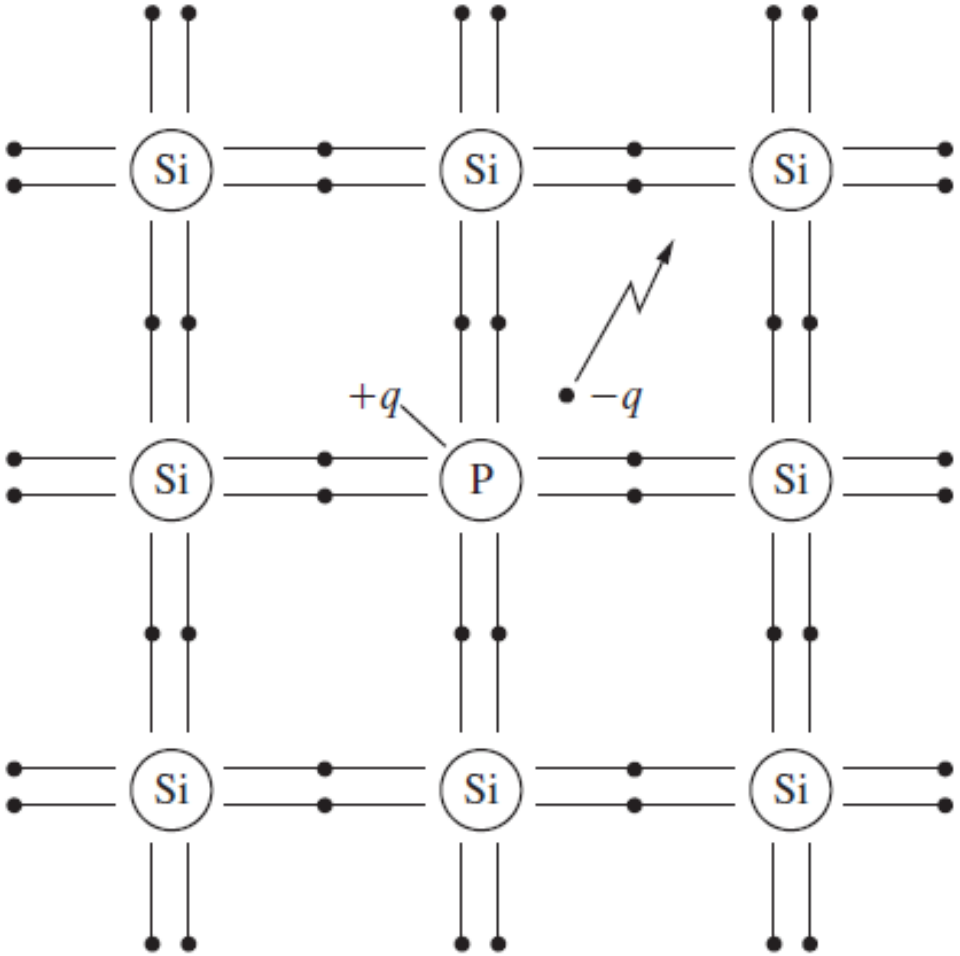
IMPURITIES IN SEMICONDUCTORS

- The real advantages of semiconductors emerge when **impurities** are added to the material in minute but well-controlled amounts.
- This process is called **impurity doping,** or just **doping,** and the material that results is termed a **doped semiconductor.**
- Impurity doping enables us to change the resistivity over a very wide range and to determine whether the electron or hole population controls the resistivity of the material.

DONOR IMPURITIES IN SILICON

- **Donor impurities** in silicon are from **column V**, having **five** valence electrons in the outer shell. The most commonly used elements are phosphorus, **arsenic**, and **antimony**.
- When a donor atom replaces a silicon atom in the crystal lattice, **four** of the five outer shell electrons fill the covalent bond structure; it then takes very little thermal energy to free the extra electron for conduction.
- At room temperature, essentially every donor atom contributes (donates) an electron for conduction. Each donor atom that becomes ionized by giving up an electron will have a net charge of $+q$ and represents an immobile fixed charge in the crystal lattice.

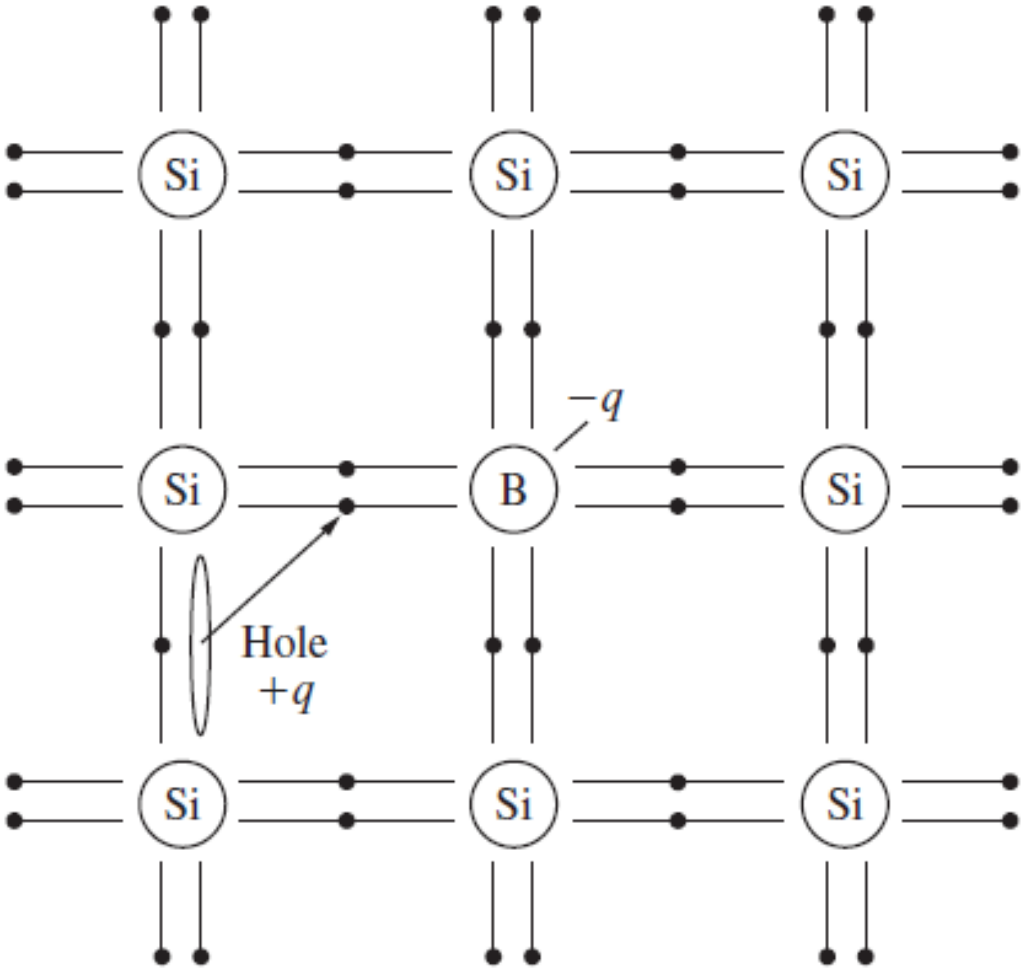
DONOR IMPURITIES IN SILICON



ACCEPTOR IMPURITIES IN SILICON

- **Acceptor impurities** in silicon are from column III and have one less electron than silicon in the outer shell. The primary acceptor impurity is **boron**
- Because boron has only three electrons in its outer shell, a vacancy exists in the bond structure, and it is easy for a nearby electron to move into this vacancy, creating another vacancy in the bond structure. This mobile vacancy represents a hole that can move through the lattice
- Each impurity atom that becomes ionized by accepting an electron has a net charge of $-q$ and is immobile in the lattice.

ACCEPTOR IMPURITIES IN SILICON



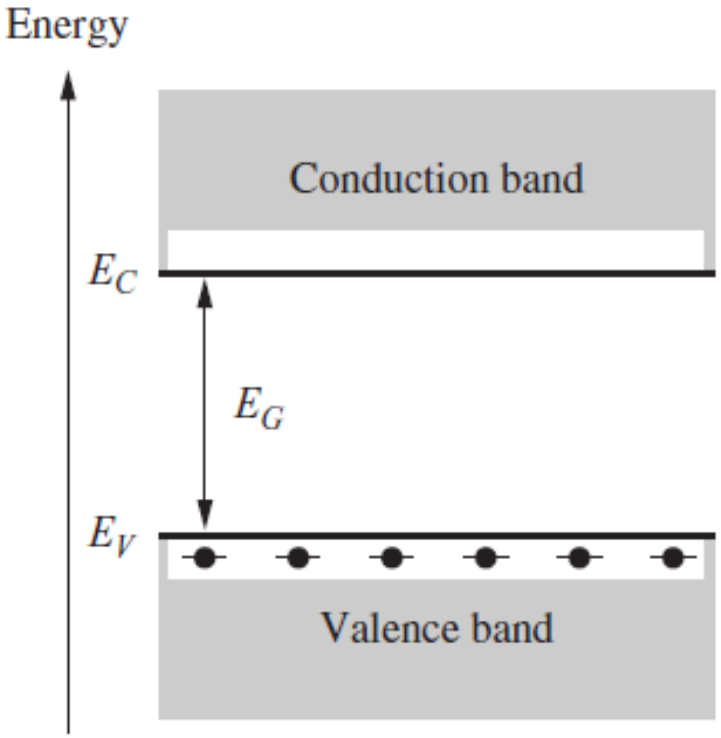
ELECTRON AND HOLE CONCENTRATIONS IN DOPED SEMICONDUCTORS

- In doped material, the electron and hole concentrations are no longer equal.
- If $n > p$, the material is called ***n*-type,**
- If $p > n$, the material is referred to as ***p*-type.**
- The carrier with the larger population is called the **majority carrier,** and the carrier with the smaller population is termed the **minority carrier.**

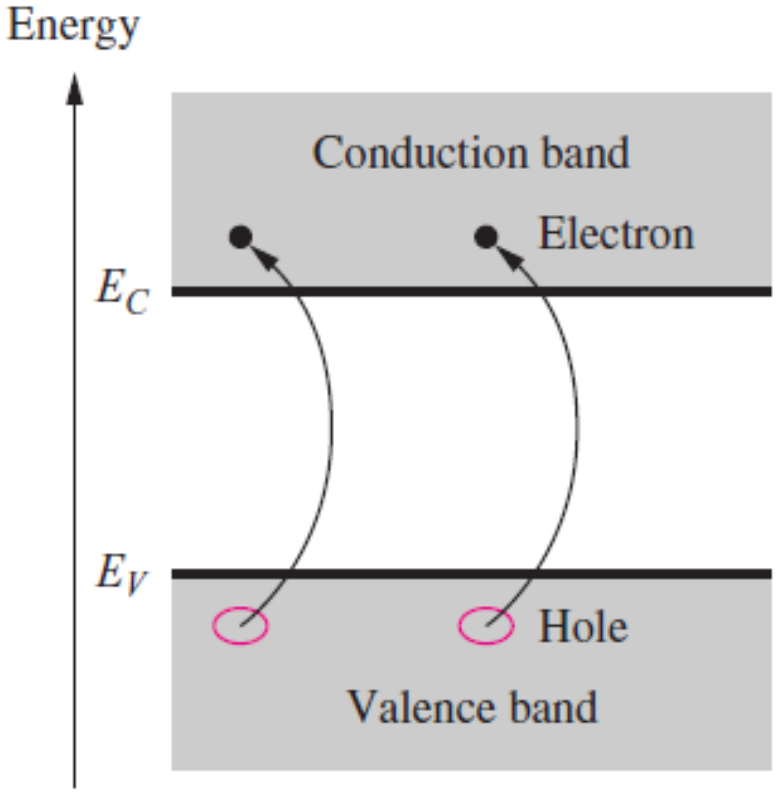
ENERGY BAND MODEL

- Energy band model of semiconductor is structured with the regions labeled **conduction band** and **valence band**.
- Energy E_V corresponds to the top edge of the valence band and represents the highest permissible energy for a valence electron.
- Energy E_C corresponds to the bottom edge of the conduction band and represents the lowest available energy level in the conduction band.
- The difference between E_C and E_V is called the ***bandgap energy EG***: $$E_G = E_C - E_V$$

ENERGY BAND MODEL FOR AN INTRINSIC SEMICONDUCTOR



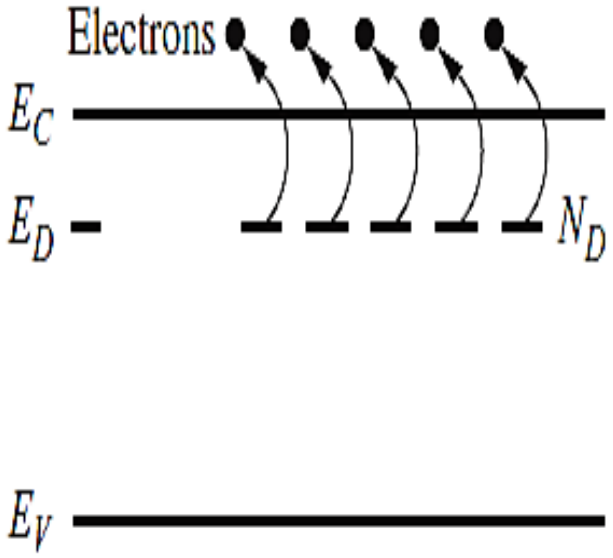
Semiconductor at 0 K with filled valence band and empty conduction band.



Creation of electron–hole pair by thermal excitation across the energy bandgap.

ENERGY BAND MODEL FOR A DOPED SEMICONDUCTOR

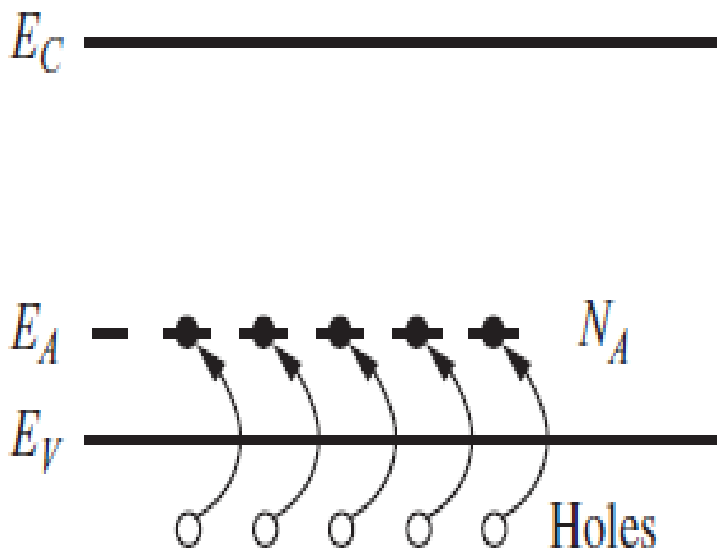
- A concentration N_D of donor atoms has been added to the semiconductor.
- The donor atoms introduce new localized energy levels within the bandgap at a **donor energy level *ED*** near the conduction band edge.
- The value of $(E_C - E_D)$ for phosphorus is approximately 0.045 eV, so it takes very little thermal energy to promote the extra electrons from the donor sites into the conduction band.



Donor level with activation energy $(E_C - E_D)$.

ENERGY BAND MODEL FOR A DOPED SEMICONDUCTOR

- A concentration N_A of acceptor atoms has been added to the semiconductor.
- The acceptor atoms introduce energy levels within the bandgap at the **acceptor energy level *EA*** near the valence band edge.
- The value of *(EA − EV)* for boron is approximately 0.044 eV, and it takes very little thermal energy to promote electrons from the valence band into the acceptor energy levels.
- At room temperature, essentially all the available acceptor sites are filled, and each promoted electron creates a hole that is free for conduction.



Acceptor level with activation energy $(E_A - E_V)$.