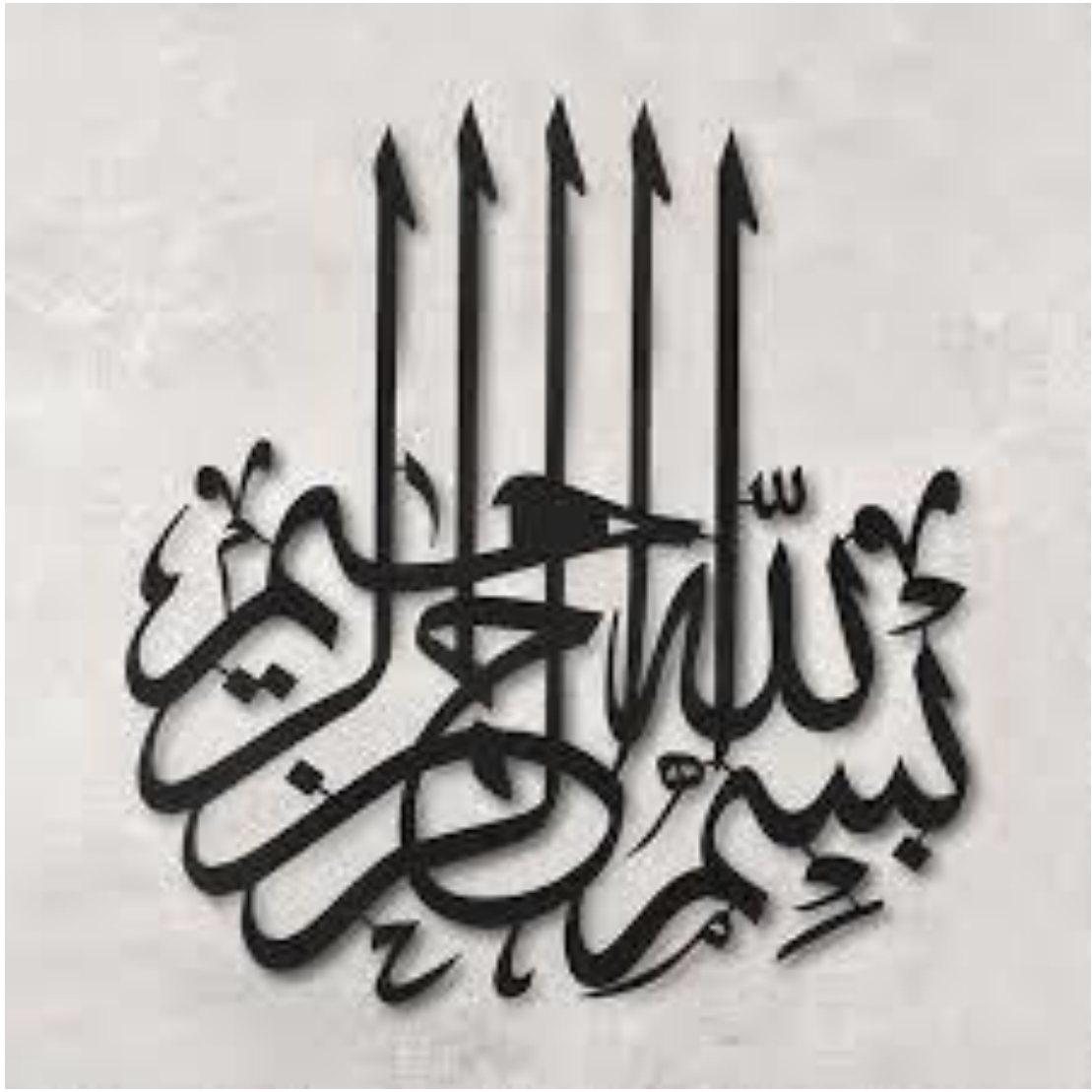
بسم الله الرحمن الرحيم

CHAPTER 3

p–n Junction

- 3.1 THERMAL EQUILIBRIUM CONDITION
- 3.2 DEPLETION REGION
- 3.3 DEPLETION CAPACITANCE
- 3.4 CURRENT-VOLTAGE CHARACTERISTICS
- 3.5 CHARGE STORAGE AND TRANSIENT BEHAVIOR
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- SUMMARY

3.7 HETEROJUNCTION

- ✓A heterojunction is defined as a junction formed between two dissimilar semiconductors.
- ✓Figure *30a* shows the energy band diagram of two isolated pieces of semiconductors prior to(پیش از) the formation of a heterojunction.
- ✓ The two semiconductors are assumed to have different energy bandgaps E_g, different dielectric permittivities ε_s, different work functions $q\phi_s$, and different electron affinities $q\chi$.

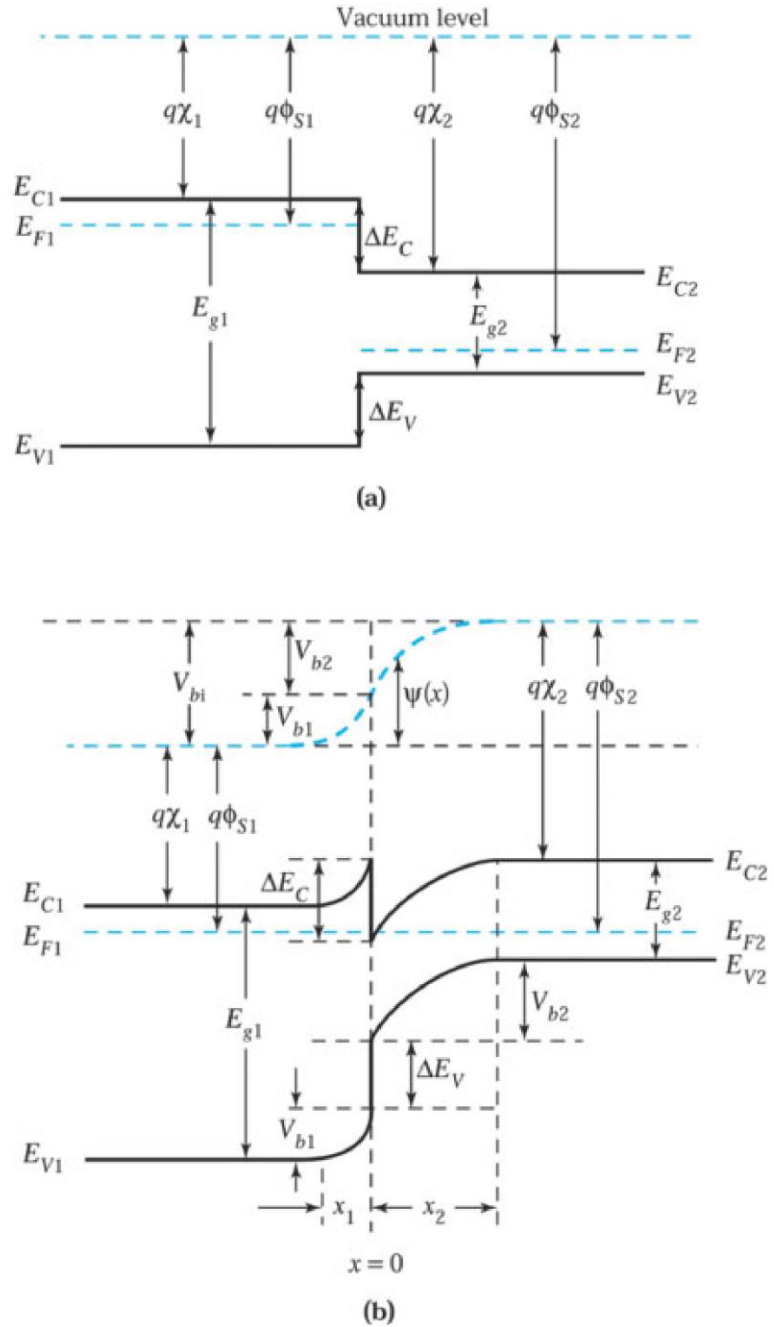

Fig. 30 (*a*) **Energy band diagram of two isolated semiconductors. (*b*) Energy band diagram of an ideal *n–p* heterojunction at thermal equilibrium.**

- ✓The work function is defined as the energy required to remove an electron from Fermi level E_F to a position just outside the material (the vacuum level).

- ✓The electron affinity is the energy required to remove an electron from the bottom of the conduction band E_C to the vacuum level.

- ✓ The difference in energy of the conduction band edges in the two semiconductors is represented by ΔE_C, and the difference in energy of the valence band edges is represented by ΔE_V.

- ✓From Fig. 30a, ΔE_C and ΔE_V can be expressed by

$$\Delta E_C = q(\chi_2 - \chi_1) \qquad (88a)$$

And

$$\Delta E_V = E_{g1} + q\chi_1 - (E_{g2} + q\chi_2) = \Delta E_g - \Delta E_C \qquad (88b)$$

where ΔE_g is the energy band difference and $\Delta E_g = E_{g1} - E_{g2}$.

✓Figure *30b* shows the equilibrium band diagram of an ideal abrupt heterojunction formed between these semiconductors.

- ✓In this diagram it is assumed that there is a negligible number of traps or generation-recombination centers at the interface of the two dissimilar semiconductors.
- ✓Note that this assumption is valid only when heterojunctions are formed between semiconductors with closely matched lattice constants.
- ✓Therefore, we must choose lattice-matched materials to satisfy the assumption.
- ✓ For example, the $Al_xGa_{1-x}\ As$ materials, with x from 0 to 1, are among the most important materials for heterojunctions.

- ✓When $x = 0$, we have *GaAs*, with a bandgap of *1.42 eV* and a lattice constant of *5.6533 Å* at *300 K*. When $x = 1$, we have *AlAs*, with a bandgap of *2.17 eV* and a lattice constant of 5.6605 Å.

- ✓ The bandgap for the ternary(سه تایی) $Al_xGa_{1-x}As$ increases with x; however, the lattice constant remains essentially constant.

- ✓Even for the extreme cases where $x = 0$ and $x = 1$, the lattice constant mismatch is only 0.1%.

- ✓There are two basic requirements in the construction of the energy band diagram:
- ✓ (a) the Fermi level must be the same on both sides of the interface in thermal equilibrium, and (b) the vacuum level must be continuous and parallel to the band edges.
- ✓Because of these requirements, the discontinuity in conduction band edges ΔE_C and valence band edges ΔE_V will be unaffected by doping as long as(تا زمانیکه) the bandgap E_g and electron affinity $q\chi$ are not functions of doping (i.e., as in nondegenerate semiconductors).

✓The total built-in potential V_{bi} can be expressed by

$$V_{bi} = V_{b1} + V_{b2}, \tag{89}$$

✓where V_{b1} and V_{b2} are the electrostatic potentials at equilibrium in semiconductors 1 and 2, respectively

SUMMARY

- ✓A *p*–*n* junction is formed when a *p*-type and an *n*-type semiconductor are brought into intimate(تنگاتنگ) contact.
- ✓The *p*–*n* junction, in addition to being a device used in many applications, is the basic building block for other semiconductor devices.
- ✓Therefore, an understanding of junction theory serves as the foundation to understanding other semiconductor devices

- ✓When a *p*–*n* junction is formed, there are uncompensated negative ions (N_A^-) on the *p*-side and uncompensated positive ions (N_D^+) on the n-side.
- ✓ Therefore, a depletion region (i.e., depletion of mobile carriers) is formed at the junction.
- ✓This region, in turn, creates an electric field.
- ✓At thermal equilibrium, the drift current due to the electric field is exactly balanced by the diffusion current due to concentration gradients of the mobile carriers on the two sides of the junction.

- ✓When a positive voltage is applied to the p-side with respect to the n-side, a large current will flow through the junction.
- ✓However, when a negative voltage is applied, virtually no current flows.
- ✓This “rectifying” behavior is the most important characteristic of *p–n* junctions.
- ✓The basic equations presented in Chapters 1 and 2 have been used to develop the ideal static and dynamic behaviors of p–n junctions.
- ✓ We derived expressions for the depletion region, the depletion capacitance, and the ideal current-voltage characteristics of p–n junctions.

- ✓ However, practical devices depart from these ideal characteristics because of carrier generation and recombination in the depletion layers, high injection under forward bias, and series-resistance effects.

- ✓ The theory and methods of calculating the effects of these departures from the ideal are discussed in detail.

- ✓ We also considered other factors that influence *p*–*n* junctions, such as minority-carrier storage, diffusion capacitance, and transient behavior in high-frequency and switching applications.

- ✓A limiting factor in the operation of *p*–*n* junctions is junction breakdown—especially that due to avalanche multiplication.
- ✓When a sufficiently large reverse voltage is applied to a *p*–*n* junction, the junction breaks down and conducts a very large current. Therefore, the breakdown voltage imposes an upper limit on the reverse bias for *p*–*n* junctions.
- ✓We derived equations for the breakdown condition of the *p*–*n* junction and showed the effect of device geometry and doping on the breakdown voltage.
- ✓A related device is the heterojunction formed between two dissimilar semiconductors.