Optoelectronic Devices

Chapter 8 *Solid State Electronic Devices, 6th Edition*
(Streetman and Banerjee)

ELEC 424
John Peeples

Optoelectronic Effect

- Photons of frequency E_g/h add to generation current
- The result is a family of reverse bias curves

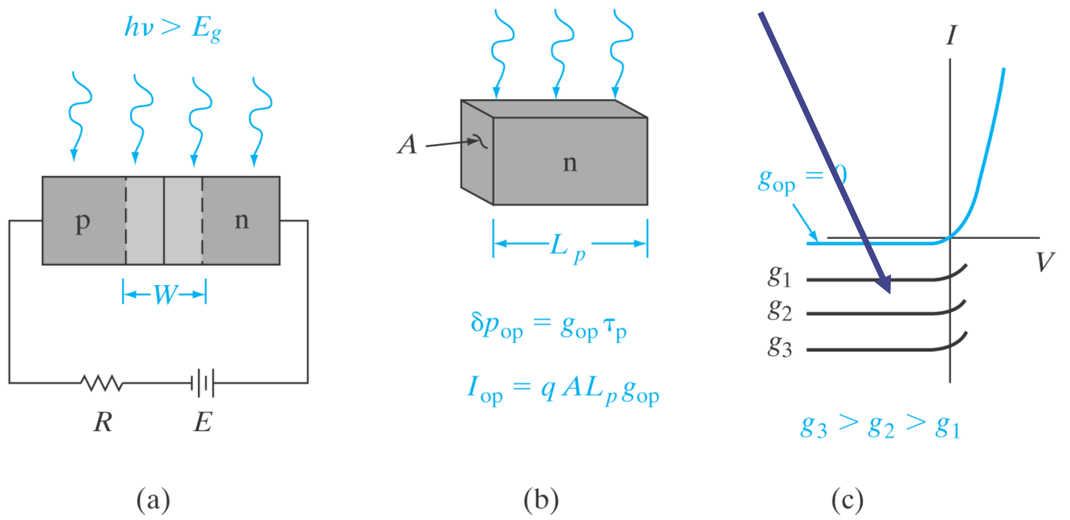

Figure 8.1

Optical generation of carriers in a p-n junction: (a) absorption of light by the device; (b) current I_{op} resulting from EHP generation within a diffusion length of the junction on the n side; (c) I–V characteristics of an illuminated junction.

Optoelectronic Devices

- Photodiodes
  - ✓Solar Cells
  - ✓Photodectectors
- Light Emitting Diodes
- Fiber Optics
- Lasers

Photoconductivity

Generation current disrupts equilibruim creating an open circuit voltage (V_{oc})

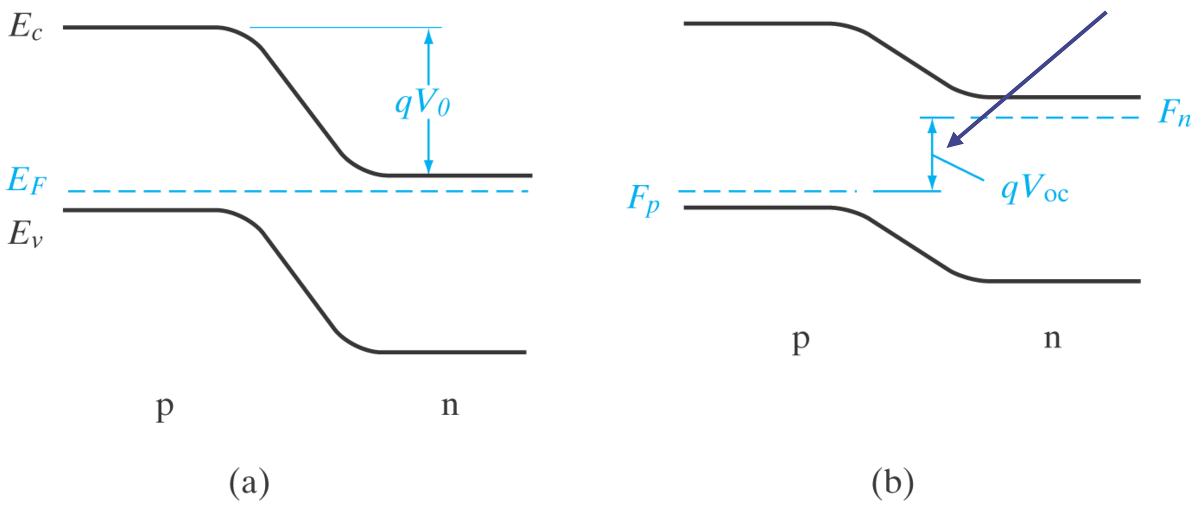

Figure 8.2

Effects of illumination on the open circuit voltage of a junction: (a) junction at equilibrium; (b) appearance of a voltage V_{oc} with illumination.

Realms of Operation

No battery
Reverse current

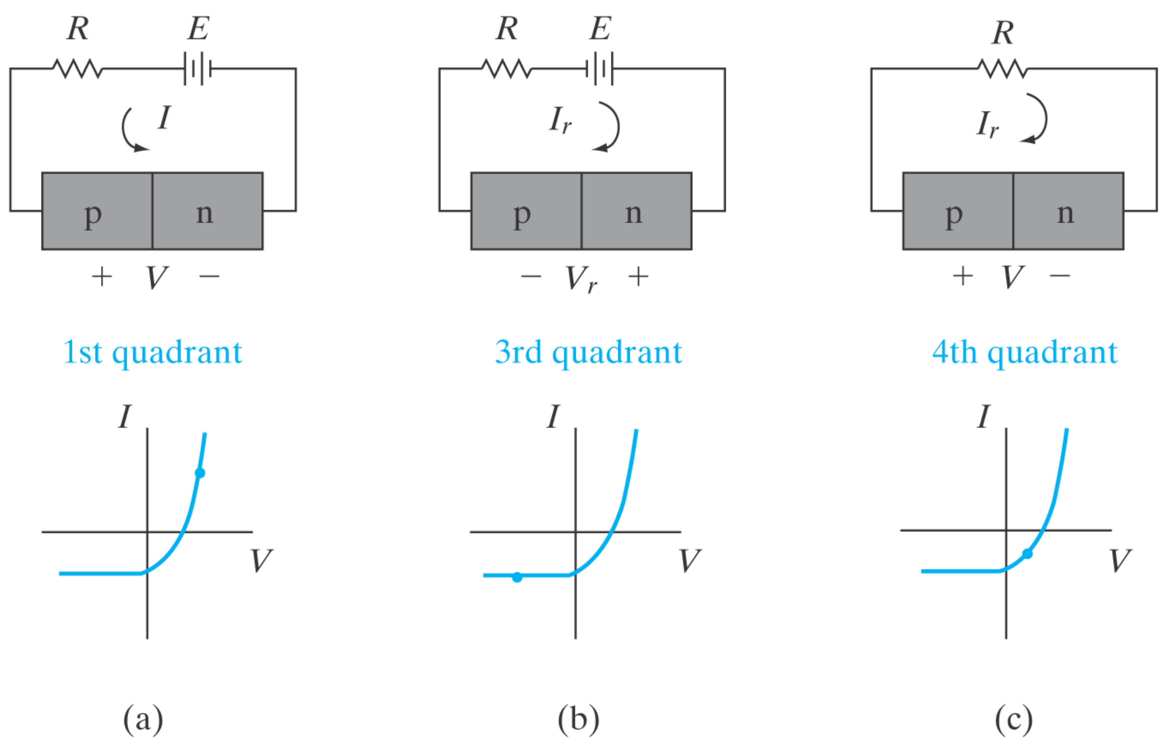

Figure 8.3

Solar Cells

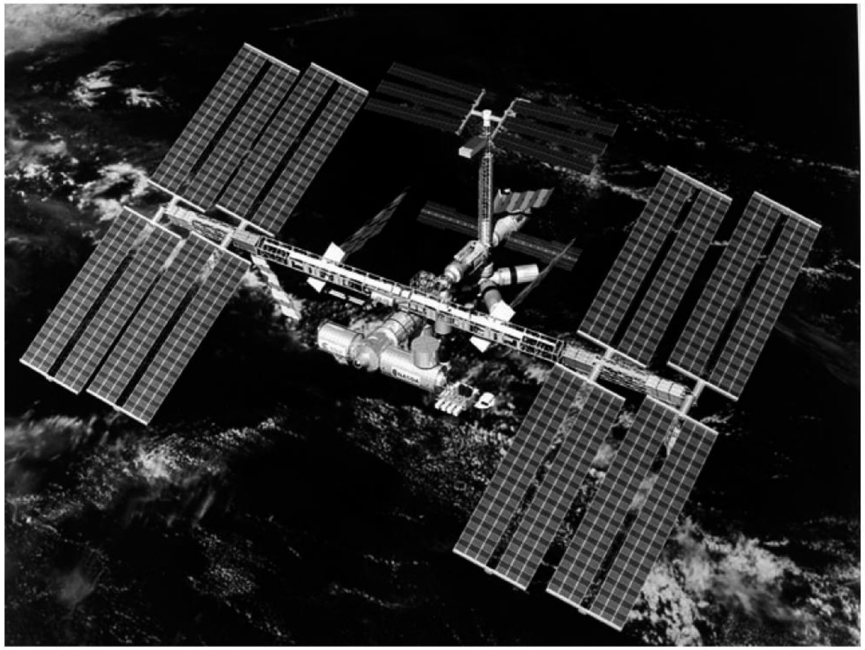

Figure 8.4

Solar cell arrays attached to the International Space Station. The solar array wings measure 74 m tip to tip. Each wing contains 32,800 solar cells and can produce 62 kW of power for the station. (Provided through the courtesy of the National Aeronautics and Space Administration.)

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Solar Cell Construction

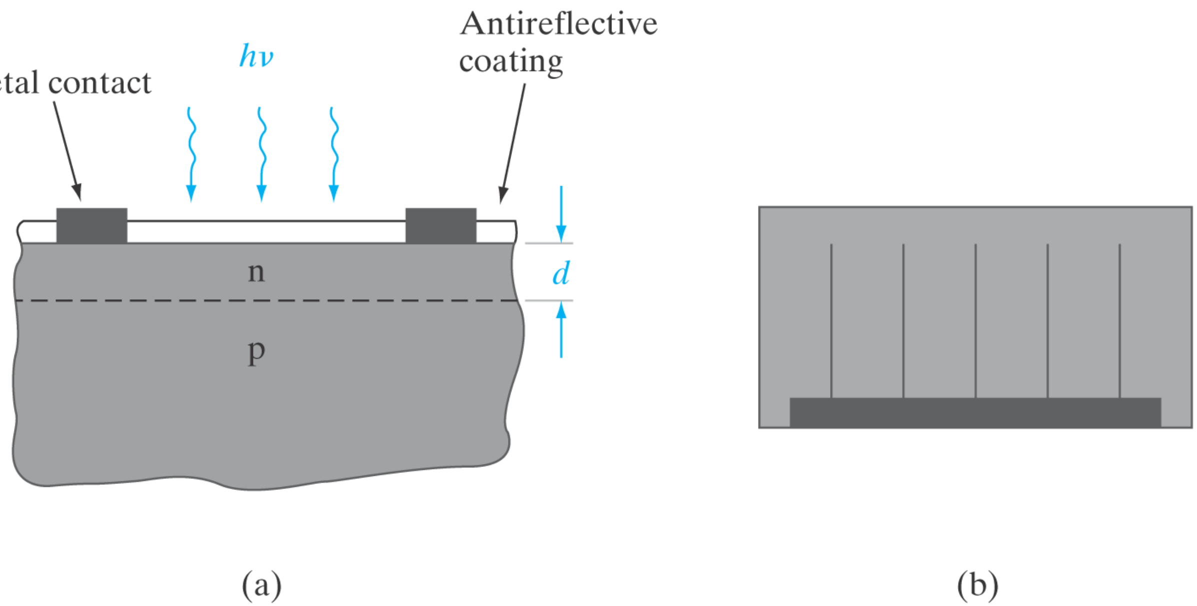


Figure 8.5

Configuration of a solar cell: (a) enlarged view of the planar junction; (b) top view, showing metal contact "fingers."

Solar Cell "Fill Factor"

- Maximum Power Figure of Merit
- V_{oc} – Bandgap Dependent
- I_{sc} – Area and Process Dependent

Notice that this is 4th Quadrant Operation
(chart flipped around for instructional purposes)

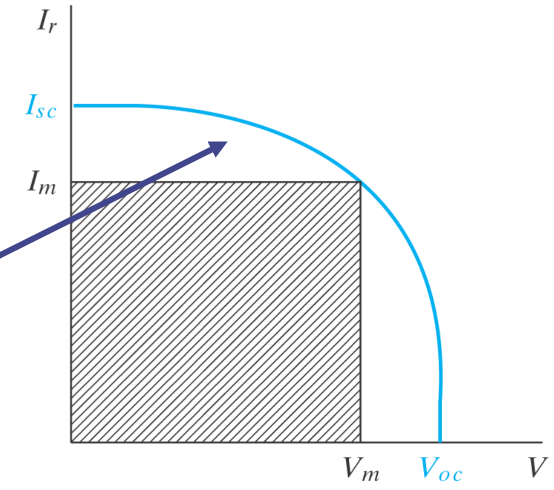


Figure 8.6

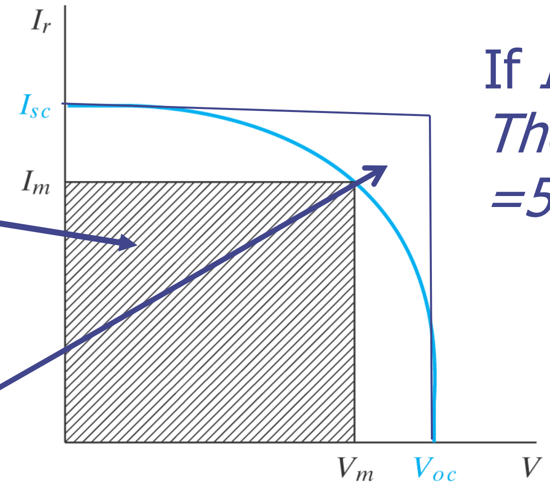
I–V characteristics of an illuminated solar cell. The maximum power rectangle is shaded.

Solar Cell "Fill Factor"

- Maximum Power Figure of Merit
- V_{oc} – Bandgap Dependent
- I_{sc} – Area and Process Dependent

Ratio
of this area

To this area



If I_{sc}=100mA and V_{oc}=0.8V,
Then Pmax=(0.8)(100)(.7)
=56mW if the fill factor is 70%.

Figure 8.6

I–V characteristics of an illuminated solar cell. The maximum power rectangle is shaded.

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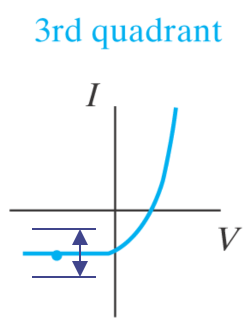
Photodetectors

- <u>3rd quadrant operation</u> (Fig 8-3)
- P-Intrinsic-N
- Impinging photons generate EHPs, changing I_o
- I_r reflects the shift in the 3rd quadrant characteristic



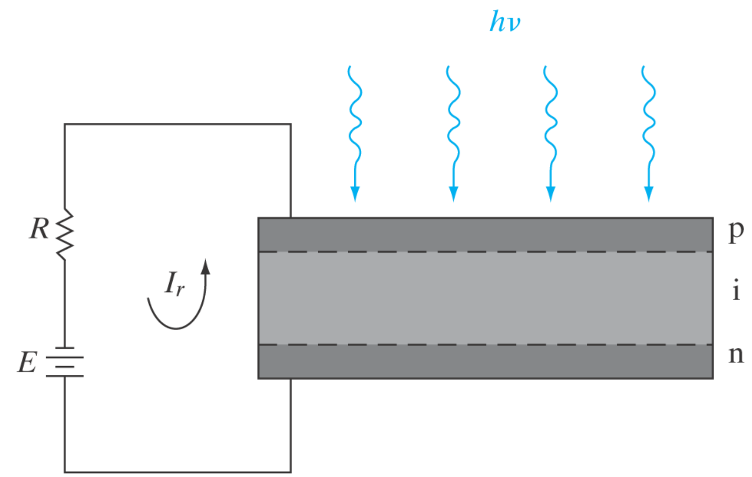


Figure 8.7

Schematic representation of a p-i-n photodiode.

Light Emitting Diodes

- Brighter LEDs enable tailight and traffic light arrays
- Colors important for displays and for communications

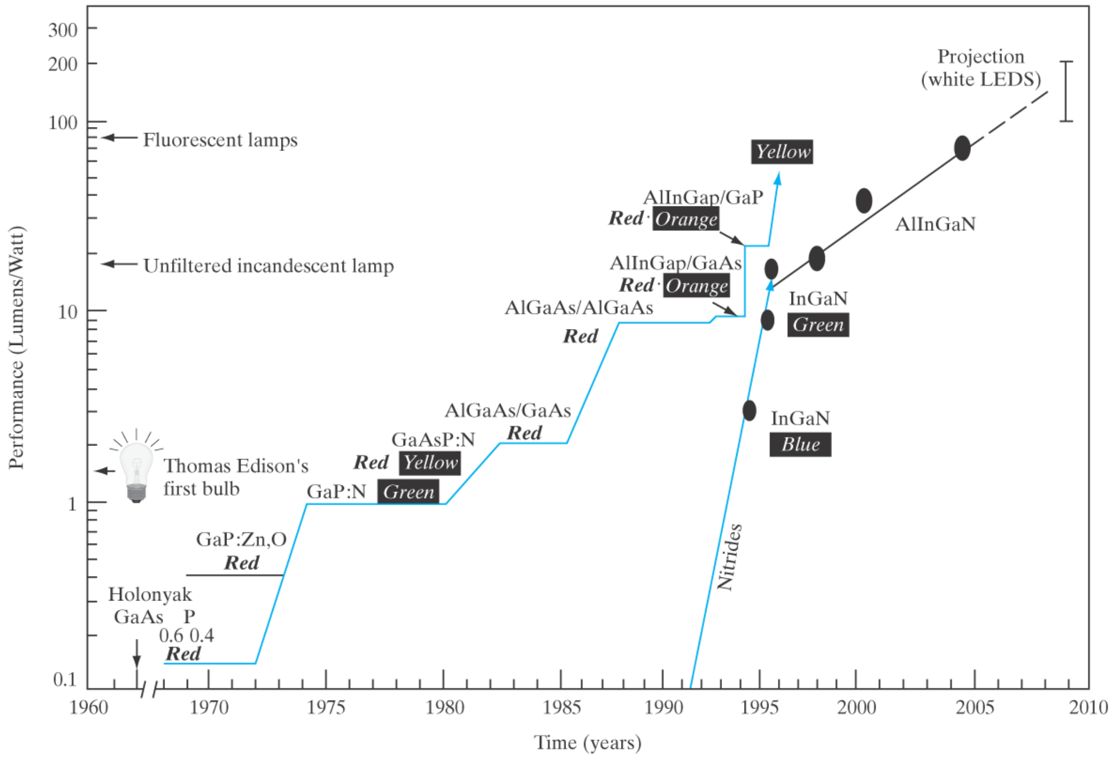


Figure 8.10

Improvement of luminous intensity of LEDs over time. [Modified from M. G. Craford, *IEEE Circuits and Devices*, p. 24, Sept. 1992.]

Light Emitting Diodes

- LEDs operate in first quadrant (forward bias)
- Carriers injected across the junction must recombine
- Recombination in indirect band gap materials generates heat
  - ✓ Si
  - ✓ Ge
- Recombination in direct band gap materials generates light (and some heat)
  - ✓ GaAs
  - ✓ GaP
  - ✓ Ternary and quaternary compounds
- Luminosity (brightness) and Color bands are important

Designer Light Emitters

- Energy varies near linearly with stoichiometry
- Energy determines emitted frequency
- Stoichiometry dictates color
- Color dictates application
  - ✓ Red, Yellow, Green – traffic lights
  - ✓ Red, Blue, Green – color displays
  - ✓ Red – tail lights
  - ✓ IR, other non-visibles – communications

$$E_g(eV) = h\nu = hc/\lambda = 1.24/\lambda(\mu m)$$

$$\lambda_{red} = 680nm = 0.68\mu m$$

$$E_g(eV) = 1.24/0.68 = 1.82eV$$

$GaA_{0.68}P_{0.32}$ or $Al_{0.32}Ga_{0.68}As$ (fig. 3-6)

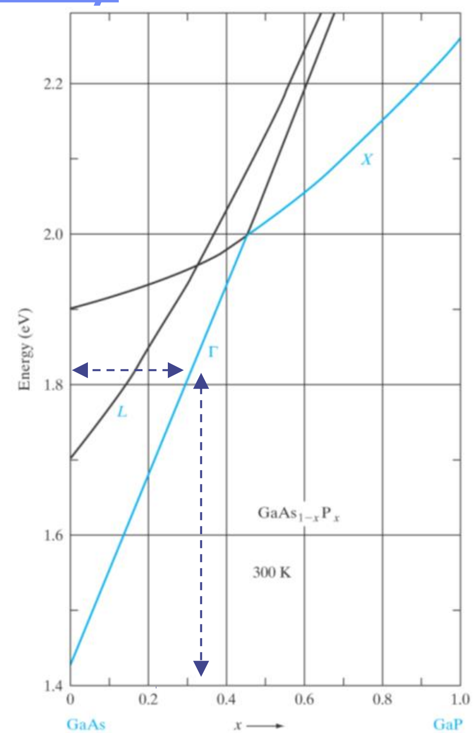


Figure 8.11

Conduction band energies as a function of alloy composition for $GaAs_{1-x}P_x$.

Light Amplification by Stimulated Emission of Radiation

- Monochromatic
- Coherent
- Highly directional

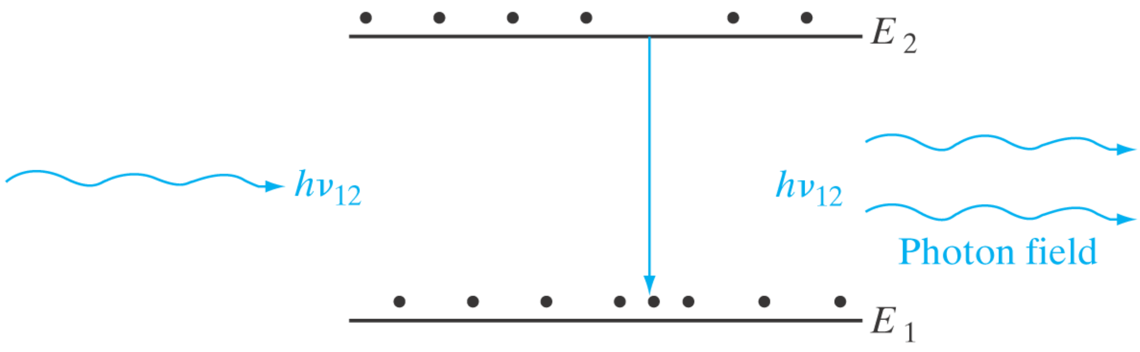


Figure 8.15

Stimulated transition of an electron from an upper state to a lower state, with accompanying photon emission.

Low to High I_F

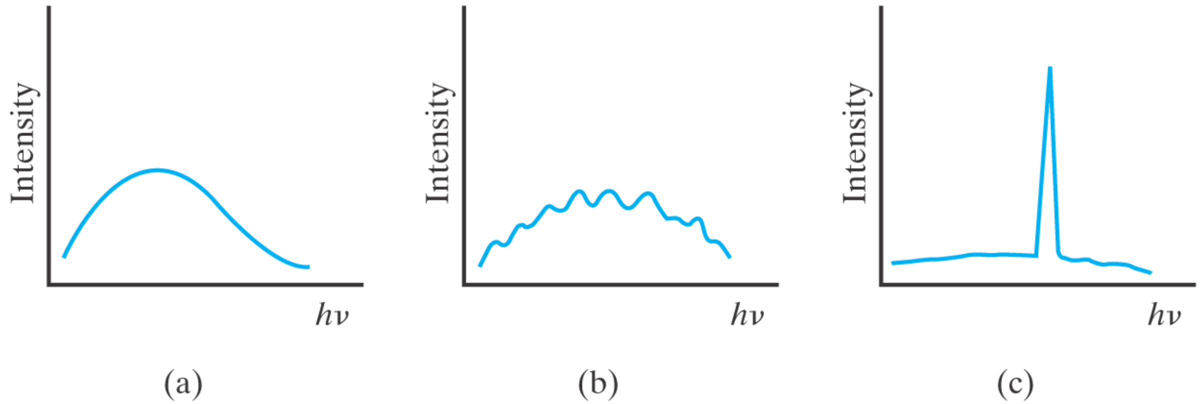


Figure 8.21

Light intensity vs. photon energy $h\nu$ for a junction laser: (a) incoherent emission below threshold; (b) laser modes at threshold; (c) dominant laser mode above threshold. The intensity scales are greatly compressed from (a) to (b) to (c).

Homojunction Lasers

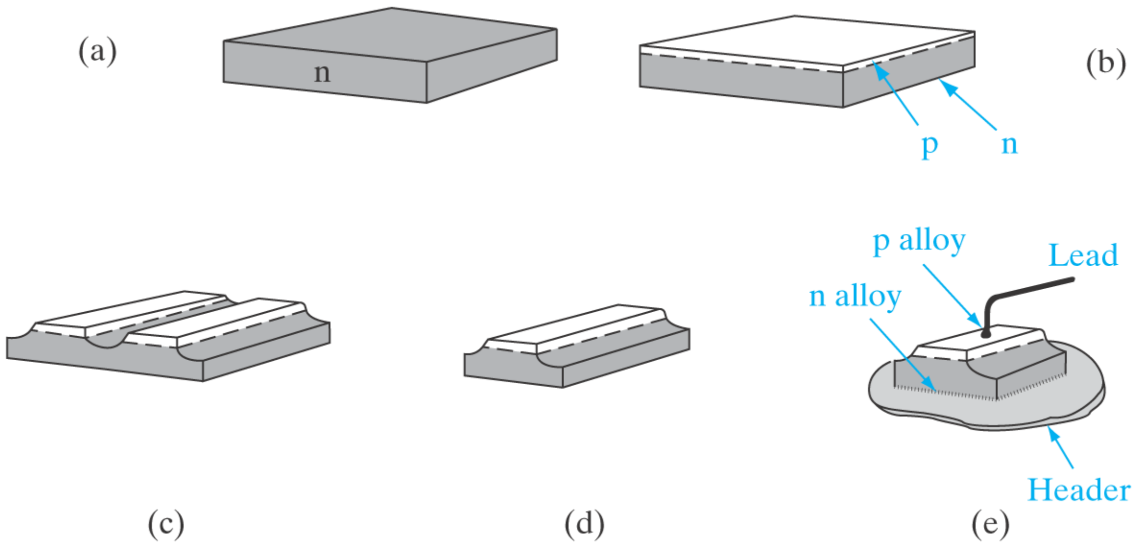


Figure 8.22

Fabrication of a simple junction laser: (a) degenerate n-type sample; (b) diffused p layer; (c) isolation of junctions by cutting or etching; (d) individual junction to be cut or cleaved into devices; (e) mounted laser structure.

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Heterojunction Lasers

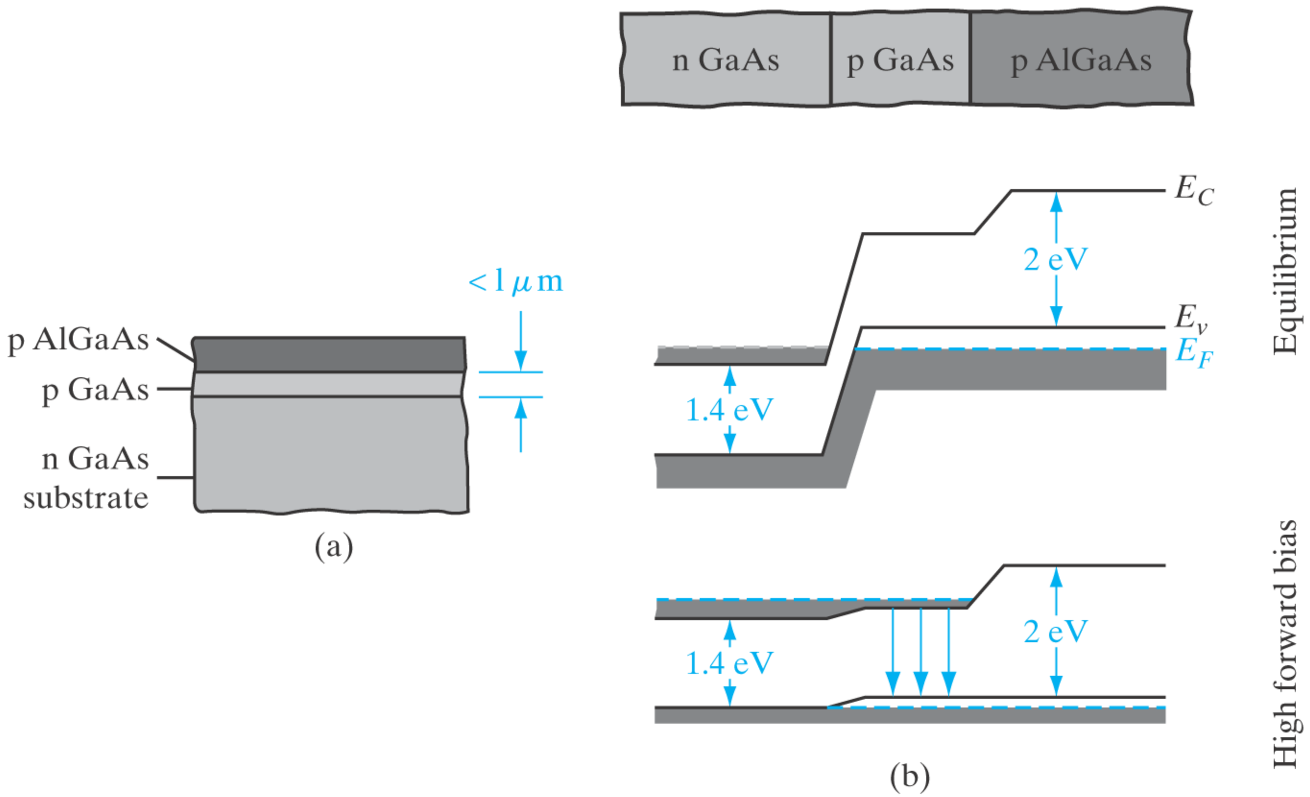

Figure 8.23

Use of a single heterojunction for carrier confinement in laser diodes: (a) AlGaAs heterojunction grown on the thin p-type GaAs layer; (b) band diagrams for the structure of (a), showing the confinement of electrons to the thin p region under bias.

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