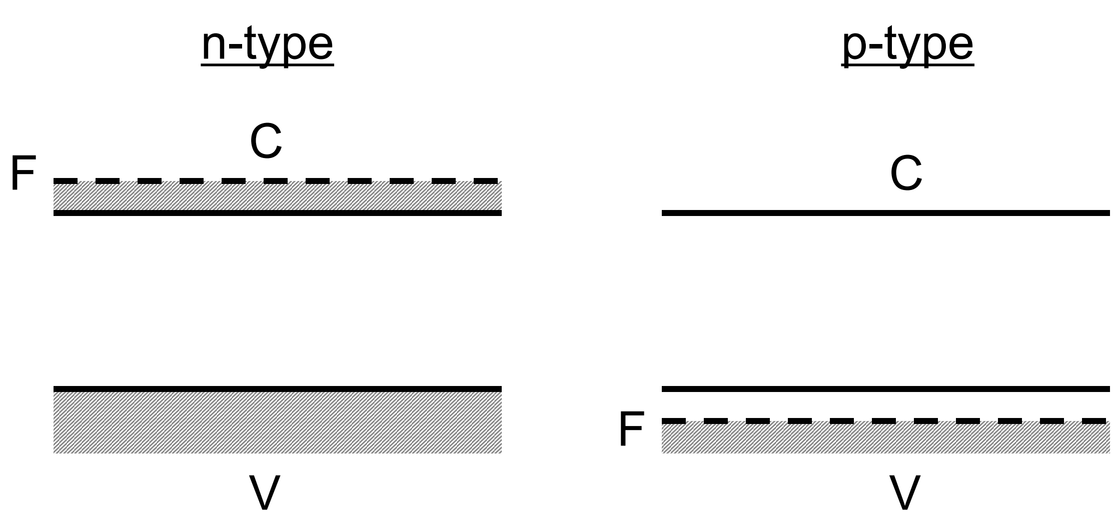
Semiconductor Lasers

- high efficiency ~50%
- compatibility with modern electronics
- small sizes

- power ~ 200mW
- current density ~ 1 kA/cm2
- not a simple TEM0,0 mode

$$e + h \rightarrow h\nu > E_g$$

Doping:
donors – more electrons (n-type)
acceptors – more holes (p-type)



C – conduction band
V – valence band
F – Fermi level

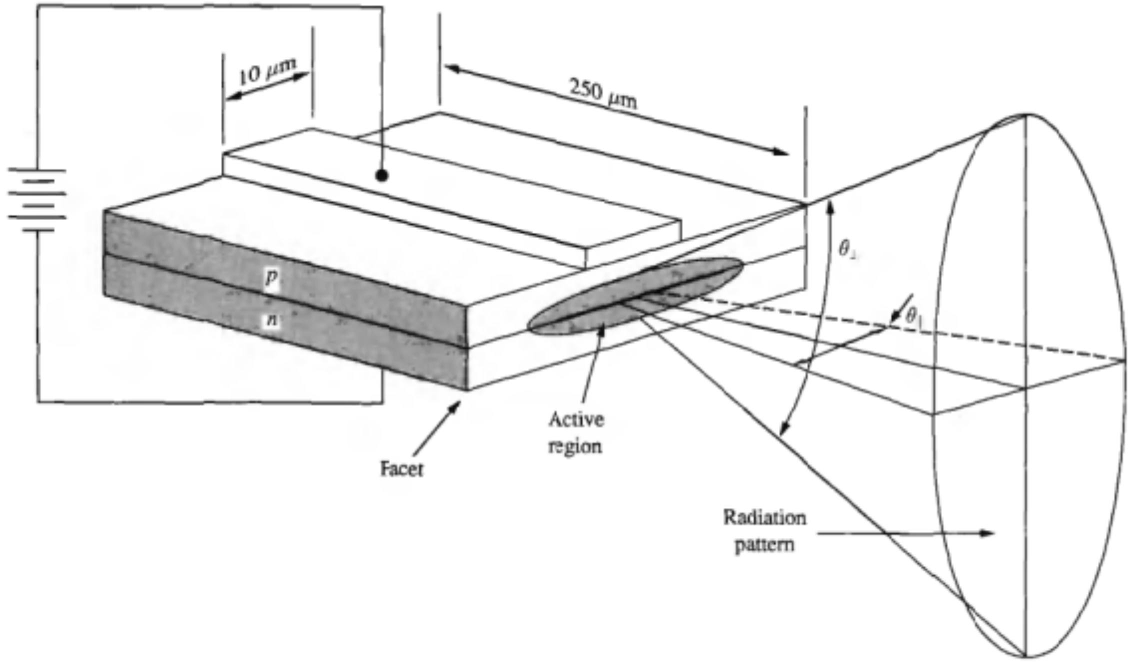
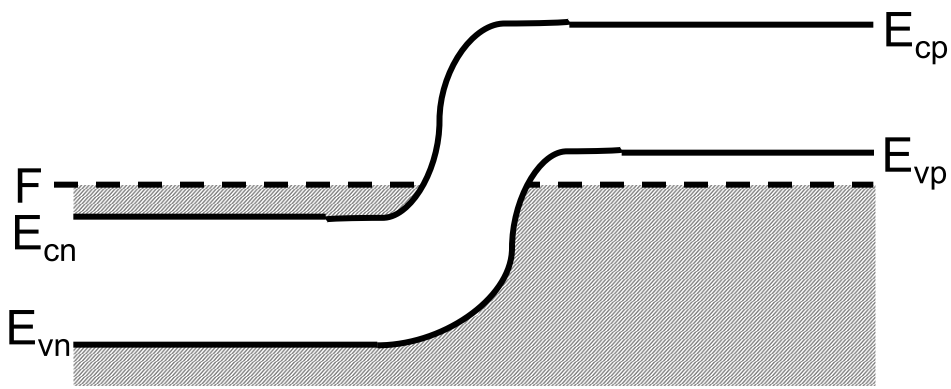


FIGURE 11.1. A generic *p-n* junction laser. The active region is at the junction of *p* and *n* regions where the current is flowing and is shown as solid black. The mode inside the semiconductor is more or less like an ellipsoid with a spatial extent much larger than the active region and is different perpendicular and parallel to the junction. This results in a radiation pattern with different spreading angles.

p-n junction in equilibrium



Intro to Semiconductor Lasers

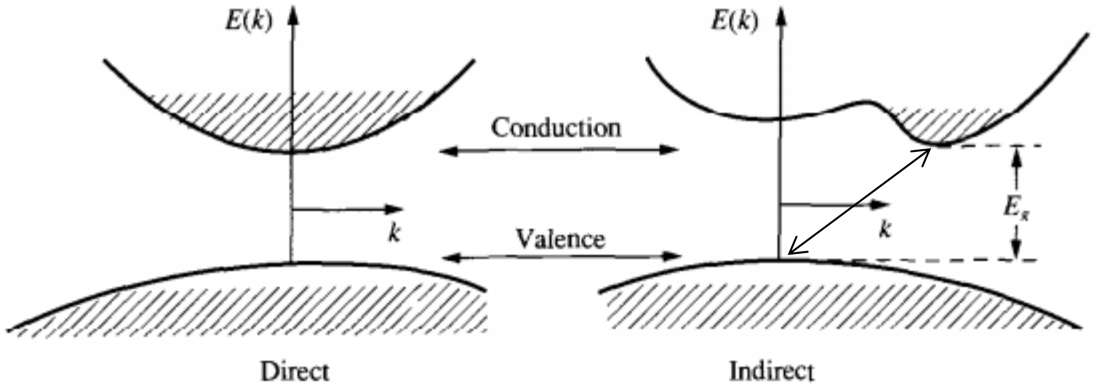


FIGURE 11.2. $E(k)$ vs. k (momentum) for direct and indirect semiconductors. The shaded areas are intended to imply states filled with an electron, and the white areas are empty.

direct: GaAs

indirect: GaP, Si, Ge

$$P_{el} = m_e^* \mathrm{u} \qquad m_e^* = 0.067 m_0 (\mathrm{GaAs})$$

$$\frac{1}{2} m_e^* \upsilon^2 = \frac{3}{2} \mathrm{k}T \Rightarrow$$

$$P_{el} = m_e^* \upsilon = \sqrt{3m^* \mathrm{k}T} \sim 3 \times 10^{-26} kg \cdot \frac{m}{s}$$

$$\mathrm{u} = \sqrt{\frac{3\mathrm{k}\,T}{m_e^*}}$$

$$P_{ph} = \frac{h}{\lambda} = \frac{6.62 \times 10^{-34}}{10^{-6} m} = 6.6 \times 10^{-23} kg \cdot \frac{m}{s}$$

$$P_{el} \gg P_{ph}$$

$$\Delta \vec{k} = \vec{k}_i - \vec{k}_f \simeq 0$$

direct transition!

Optical transitions in indirect materials have less oscillator strength. Non-radiative release of energy dominates the radiative

Homojunction Lasers

(a)

(b)

(c)

(d)

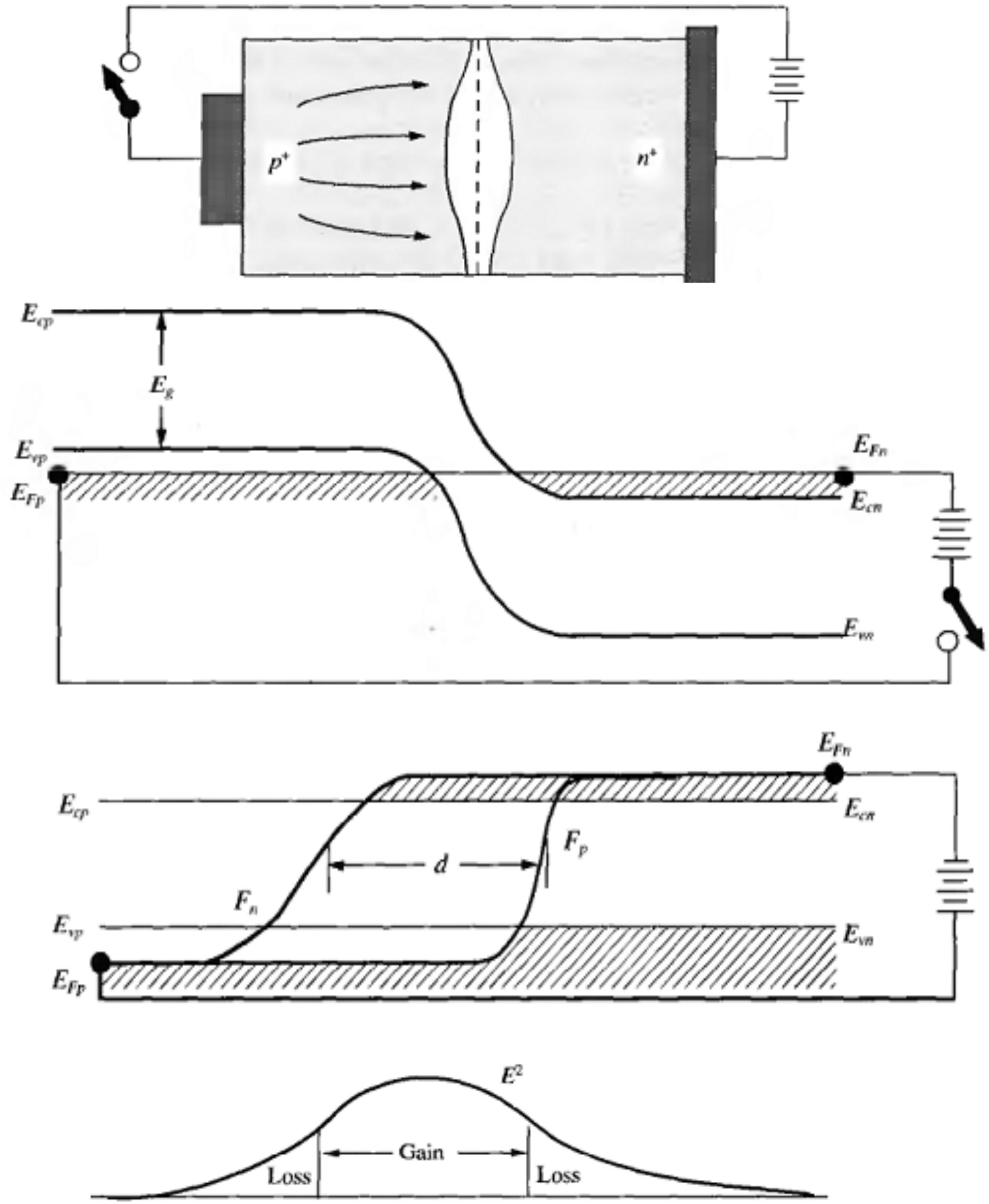


FIGURE 11.10. The homojunction laser: (a) shows a cross section of the junction with the bowed area being due to current spreading; (b) and (c) show the band diagram in equilibrium and with injected current; (d) illustrates the electromagnetic mode experiencing gain and loss.

Heterojunction Lasers

- better control
- lower threshold current

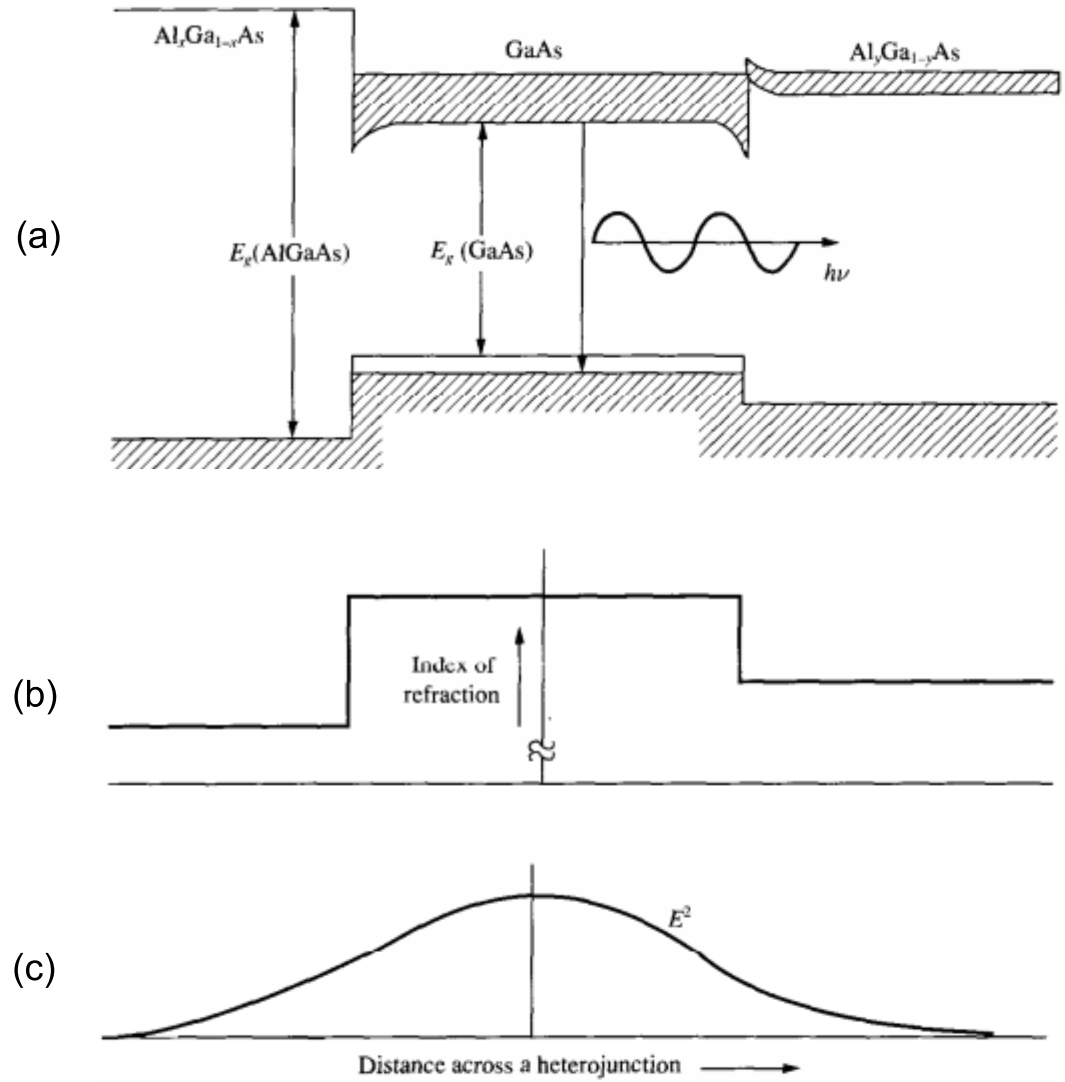
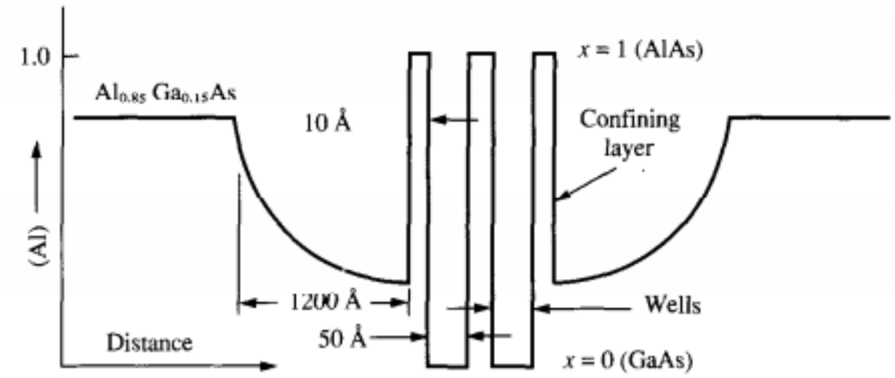
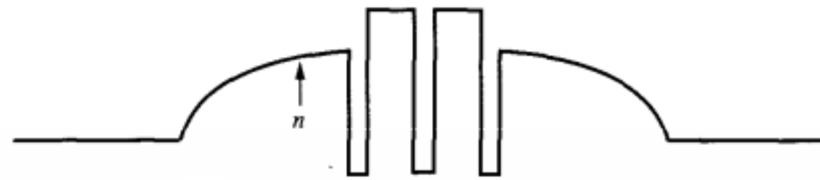


FIGURE 11.13. (a) The band diagram for a forward-biased heterostructure, (b) the refractive index, and (c) a sketch of the light intensity in the vicinity of the active region.

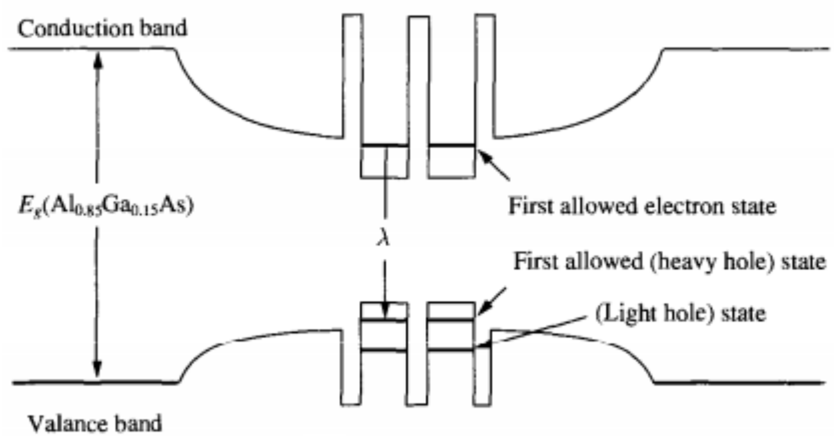
Quantum-Well Lasers



(a) Aluminum concentration at the junction



(b) Variation of the index of refraction



(c) Band diagram

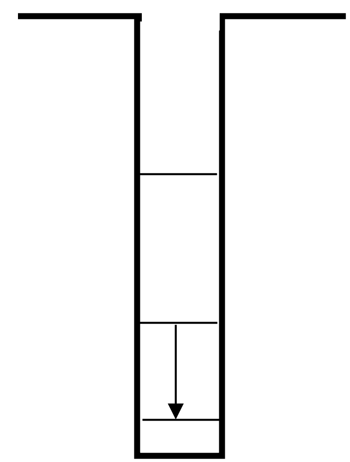


FIGURE 11.17. An application of quantum size effects for junction lasers: (a) shows the typical variation of the aluminum concentration as a function of depth in the junction. The number of wells can be changed from one to many. (b) and (c) show the effect of the aluminum concentration on the index of refraction and the band gap.