# Laser Structure

Photons with a well defined energy are selectlively confined in the semiconductor structure
When photons are emitted only a small fractions allowed to leave the optical cavity.

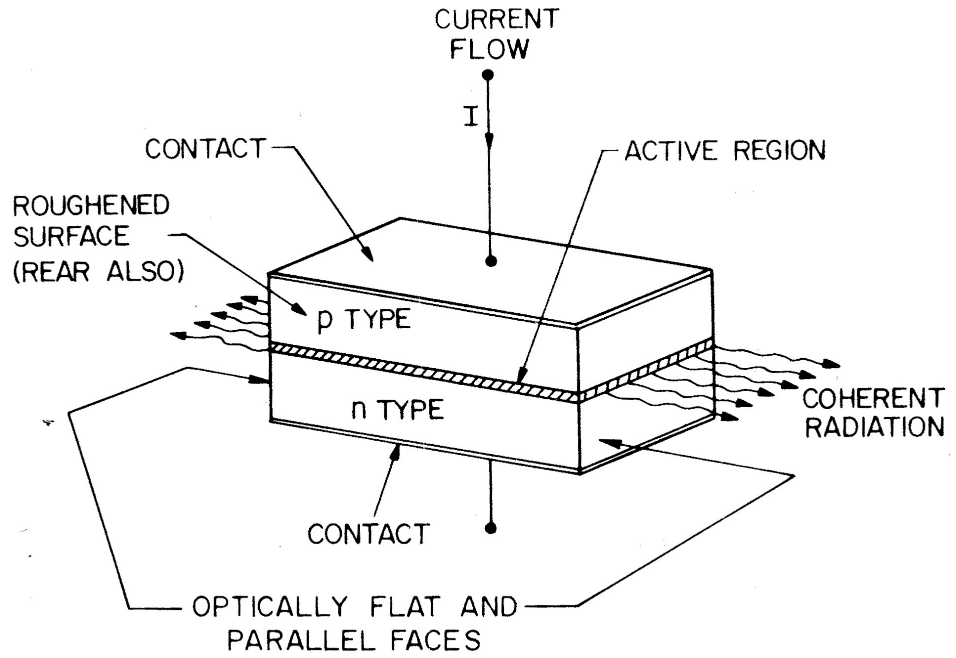
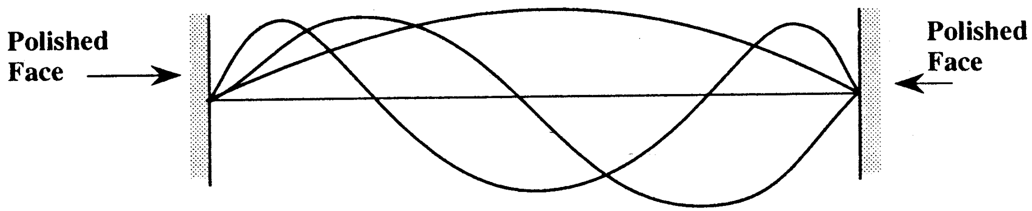


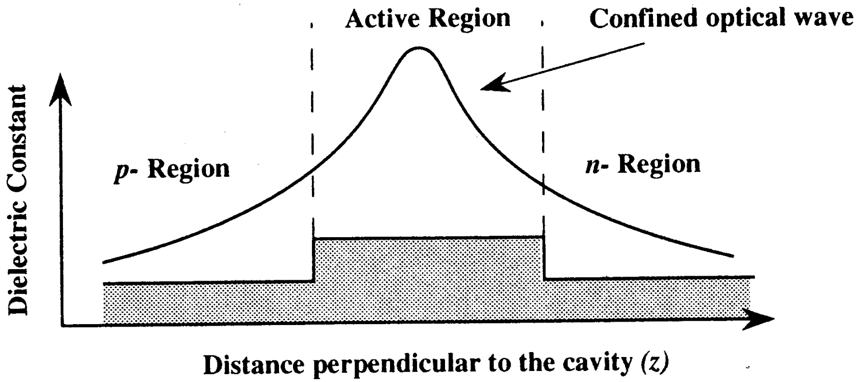

**Fig. 26** Basic structure of a junction laser in the form of a Fabry–Perot cavity.

A pair of parallel planes are cleaved or polished perpendicular to the plane junction, while the two remaining sides are roughened to eliminate lasing in the directions other than the main one. The structure is called a Fabry-Perot cavity.

# Fabry-Perot Cavity




(b)




The important ingredient in the cavity is a polished mirror surface which assures that resonant modes are produced in the cavity. These cavity resonant modes are those for which the wave vectors of the photon satisfy the relation $L=m\lambda/2$ wiht $\lambda=\lambda_0/\_$.

The optical confinement in the active region is obtain by using caldding layers (materials with different dielectric costant).

# α, Loss and Gain

The photon current associated with an electromagnetic wave travelling through a semiconductor is described by

$$I_{ph} = I_{ph}^{0} \exp(-\alpha x)$$

If electrons are pumped in the conduction band and holes in the valence band, the electron-hole recombination process (photon emission) can be stronger than the reverse process of electron-hole generation (photon absorption).
In general the gain coefficient is defined by
gain= emission coefficient-α.
If $f_e(E_e)$ and $f_h(E_h)$ are the electron and hole distributions, the emission coefficient depends upon the product $f_e(E_e)$ and $f_h(E_h)$ while the absorption coefficient depends upon the product $(1-f_e(E_e))$ and $(1-f_h(E_h))$. The gain is

$$g(\hbar\omega) \propto f_e(E_e)\cdot f_h(E_h) - \{1 - f_e(E_e)\}\{1 - f_h(E_h)\} = \{f_e(E_e) + f_h(E_h)\} - 1$$

The condition for positive gain requires 'inversion' of the semiconductor system

$$\{f_e(E_e) + f_h(E_h)\} > 1$$

If $f_e(E_e)=0=f_h(E_h)$ the gain is $=-\alpha$.

# $J_{th}$

The light output from a laser diode displays a rather abrupt change in the behaviour below the ‘threshold’ condition and above this condition. The threshold condition is usually defined as the condition where the gain overcomes the losses in the active region for any photon energy.

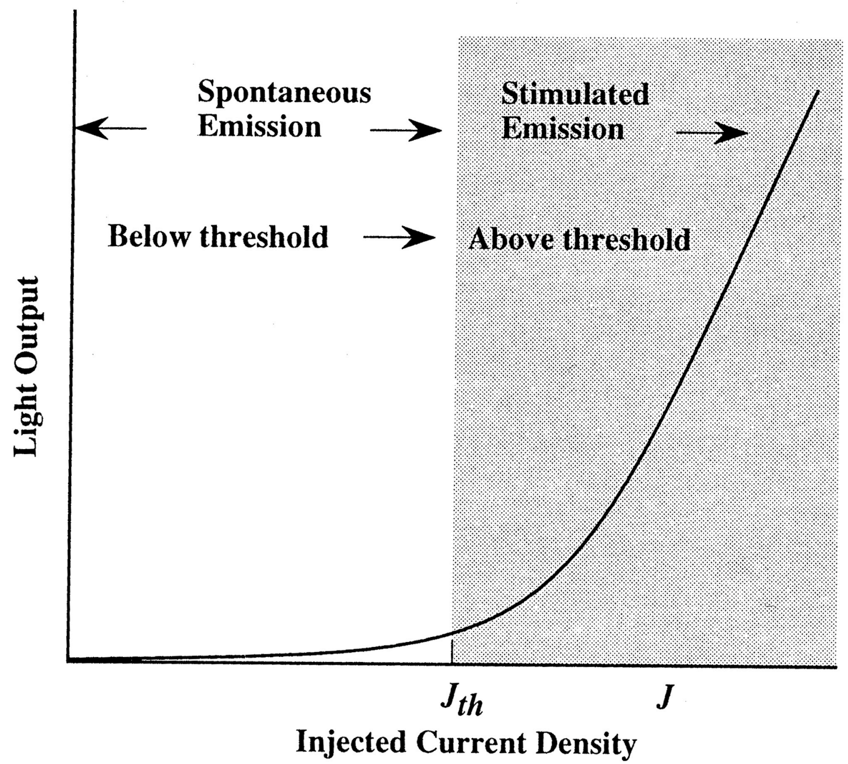



Figure 11.17: The light output as a function of current injection in a semiconductor laser. Above threshold, the presence of a high photon density causes stimulated emission to dominate.

# Regions of Laser Operation

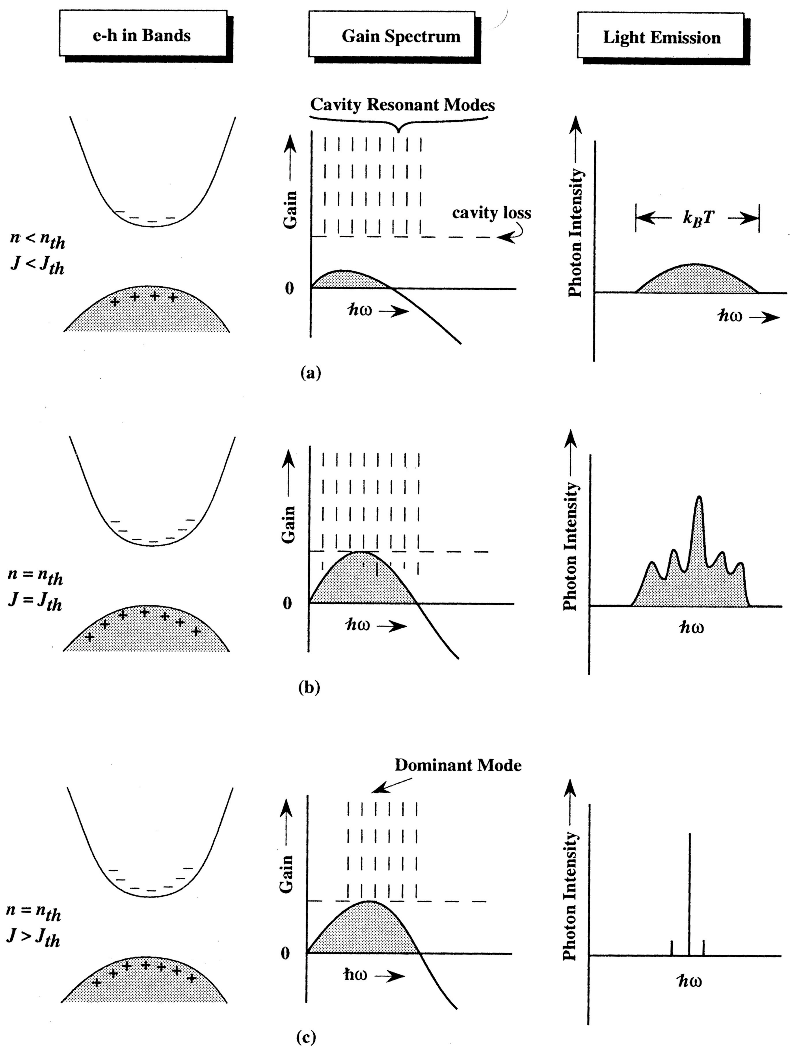



Figure 11.18: (a) The laser below threshold. The gain is less than the cavity loss and the light emission is broad as in an LED: (b) The laser at threshold. A few modes start to dominate the emission spectrum: (c) The laser above threshold. The gain spectrum does not change but, due to the stimulated emission, a dominant mode takes over the light emission.

# Homo vs Heterostructure Laser

For the homostructure (e.g. GaAs p-n junction), the threshold current density ($J_{th}$) increases rapidly with increasing T ($J_{th}=5\times10^4$ A/cm$^2$ at RT).
To reduce $J_{th}$, heterostructure laser has been proposed .

Cavity gain = $g(\hbar\omega)\Gamma$

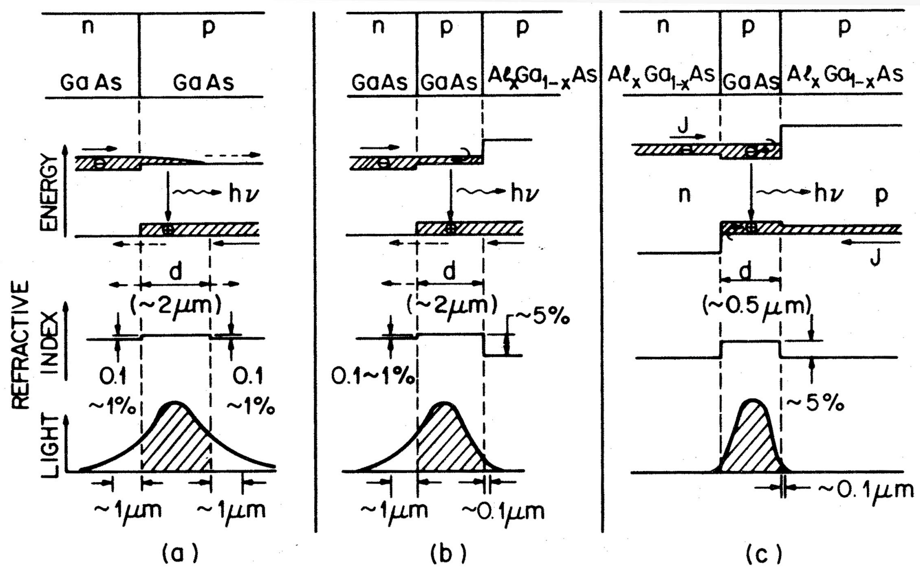



**Fig. 27** Comparison of some characteristics of (*a*) homostructure, (*b*) single-heterostructure, and (*c*) double-heterostructure lasers. The top row shows energy-band diagrams under forward bias. The refractive index change for GaAs/$Al_xGa_{1-x}As$ is about 5%. The change across a homostructure is less than 1%. The confinement of light is shown in the bottom row. (After Panish, Hayashi, and Sumski, Ref. 48.)

With the double heterostructure, the carriers are confined in the active region by the heterojunction potential barriers on both sides, and the optical field is also confined within the active region by the abrupt reduction of the refractive index outside the active region.

# $J_{th}$ vs T

These confinements can enhance the stimulated emission and substantially reduce Jth.

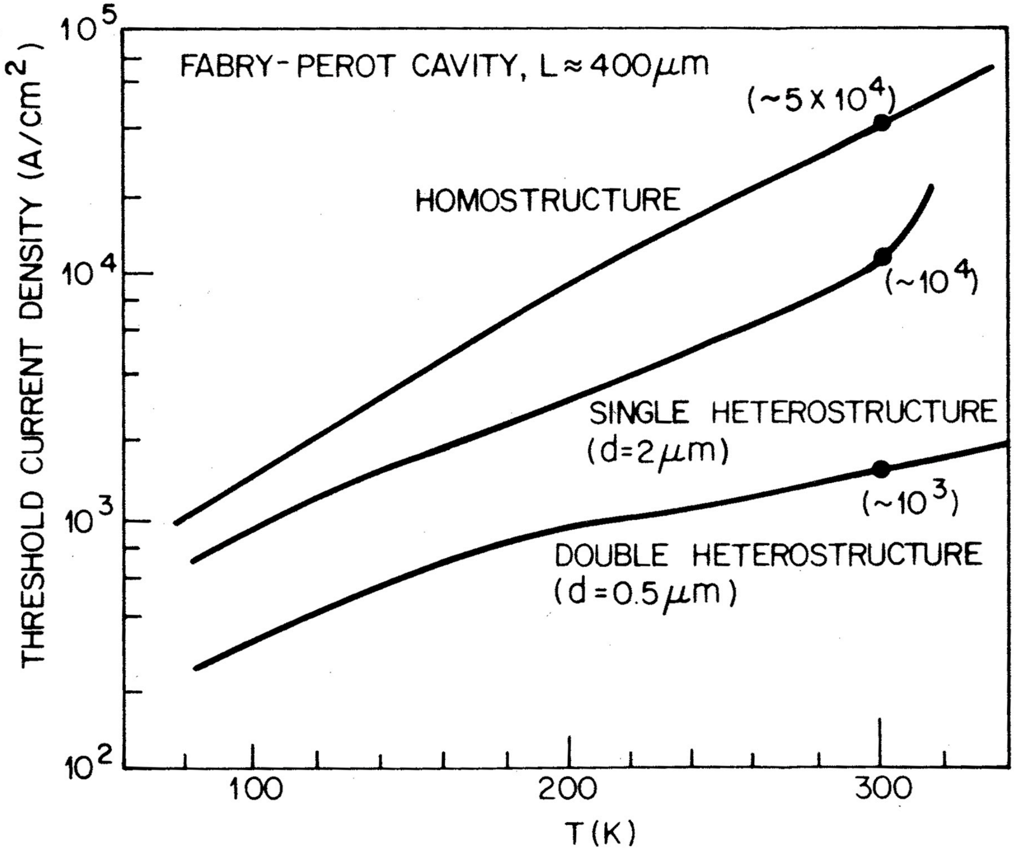
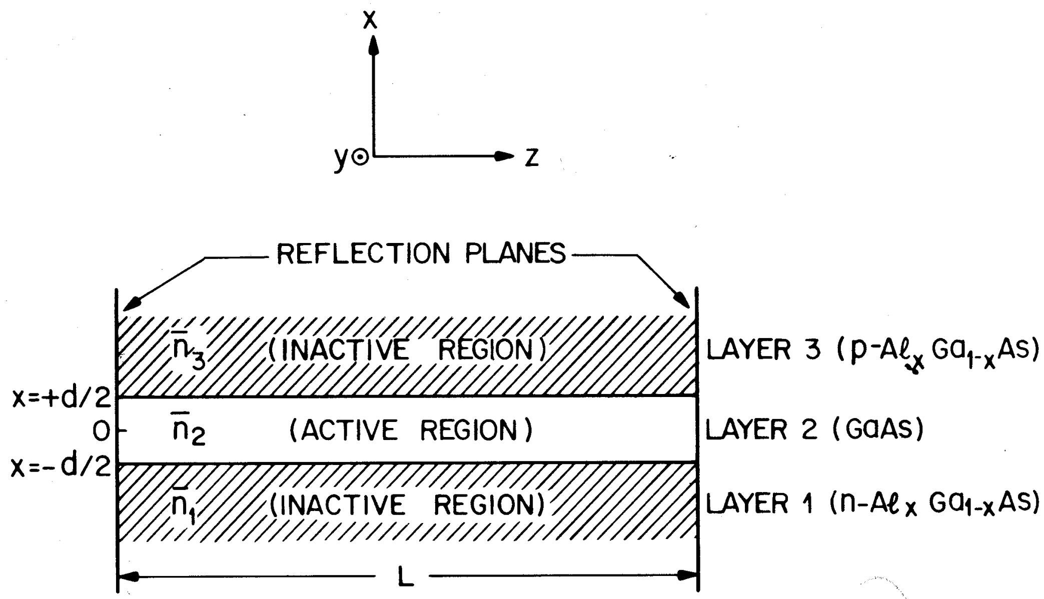


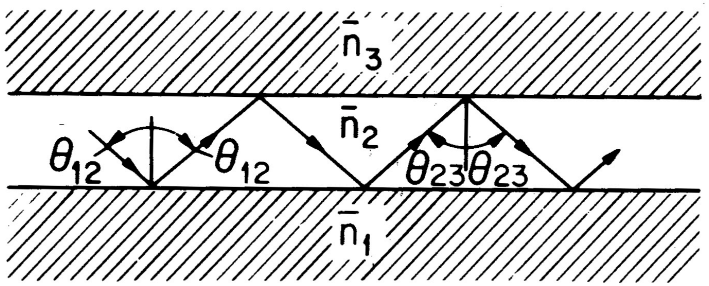

**Fig. 28** Threshold current density versus temperature for three laser structures in Fig. 27. (After Panish, Hayashi, and Sumski, Ref. 48.)

# Waveguiding

In a DH laser, the light is confined and guided by the dielectric waveguide. The active layer is sandwiched between two inactive layers.  Under the condition

$$\bar{n}_2 > \bar{n}_1 \geq \bar{n}_3$$




(b)

$$\vartheta_{12} = \sin^{-1}\left(\frac{\bar{n}_1}{\bar{n}_2}\right) \text{ and } \vartheta_{23} = \sin^{-1}\left(\frac{\bar{n}_2}{\bar{n}_3}\right)$$

# Waveguiding

Therefore when the refractive index in the active region is larger than the index of its surrounding layers, the propagation of e. m. radiation is guided in a direction parallel to the layer interfaces.

$n_2$ (GaAs)=3.6

$n_1$(AlGaAs with x=0.3) ≈3.385

$\theta_{12}$=70°

For the homostructure laser, the difference in the refractive index between the center of the waveguiding layer and the adjacent layers is only 0.1 to about 1%. For heterostructure lasers, the refractive index steps at each heterojunction can be made larger (≈10%) and provide a well-defined waveguided.

We now define a confinement factor $\Gamma$, which is tha ratio of the light intensity within tthe active layer to the sum of light intensity both within and outside the active layer.

$$\Gamma \cong 1 - \exp(-C\Delta\overline{n}d)$$

It is clear that larger is the refractive index difference and the cavity thickness (d) larger is the confinement factor.