Semiconductor Lasers

Homojunction semiconductor laser – 1962

Demonstrated by 4 research groups.

- R.N. Hall : GE Schenectady, NY
- M.I. Nathan : IBM
- N. Holonyak : GE Syracuse
- Robert H. Rediker, Lincoln Lab

Heterojunction injection laser – 1963

Proposed by H. kroemer 1963

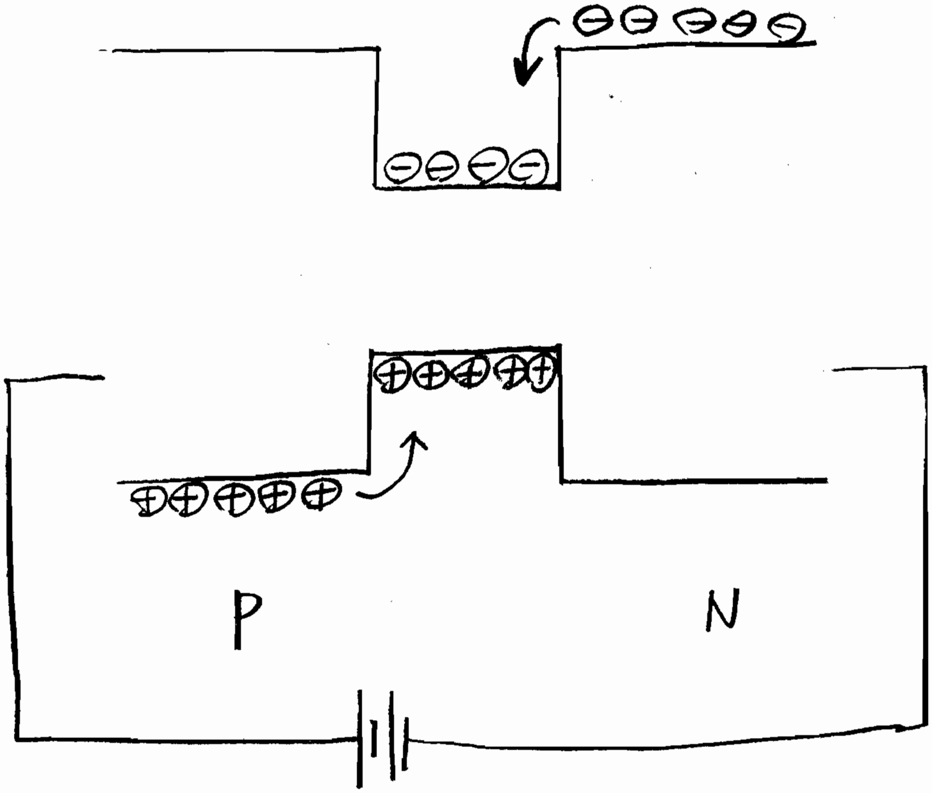
Double Heterostructure laser – 1970

Zh. I. Alferov

Quantum well lasers – late 1970's

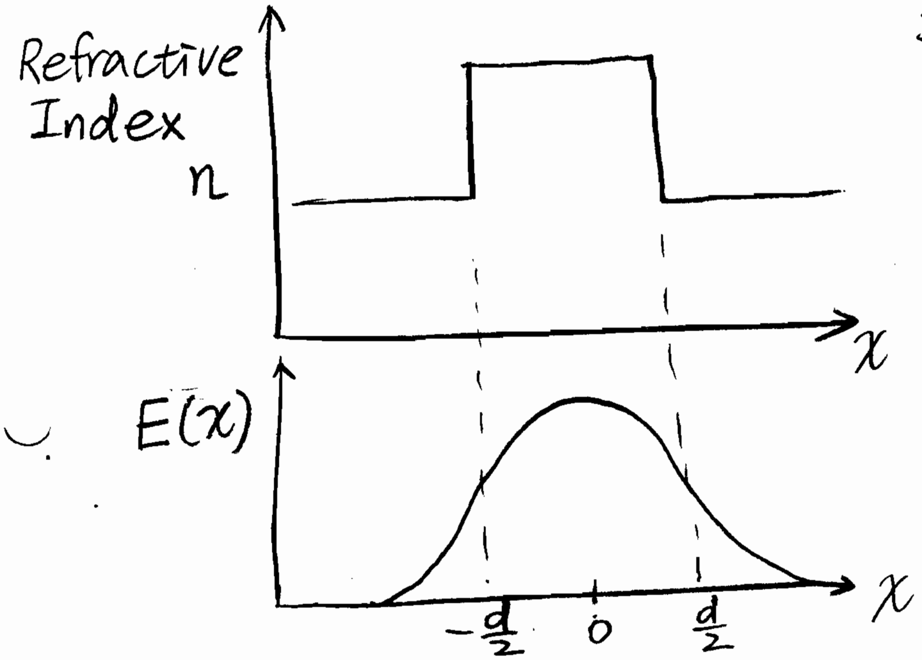
Strained QW lasers — late 1980's

Double Heterostructure (DH)



High concentration of both electrons and holes in the smaller-bandgap active region

→ carrier confinement



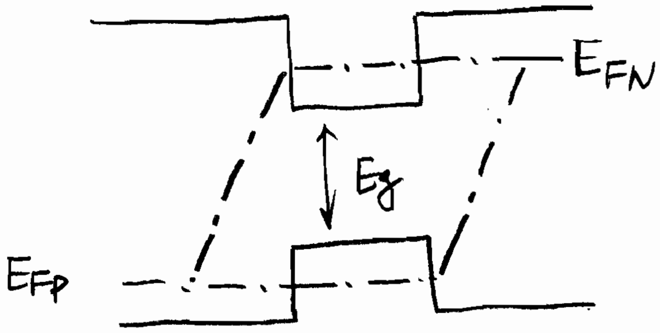
Small bandgap
→ higher n

⇒ Optical confinement

Confinement Factor

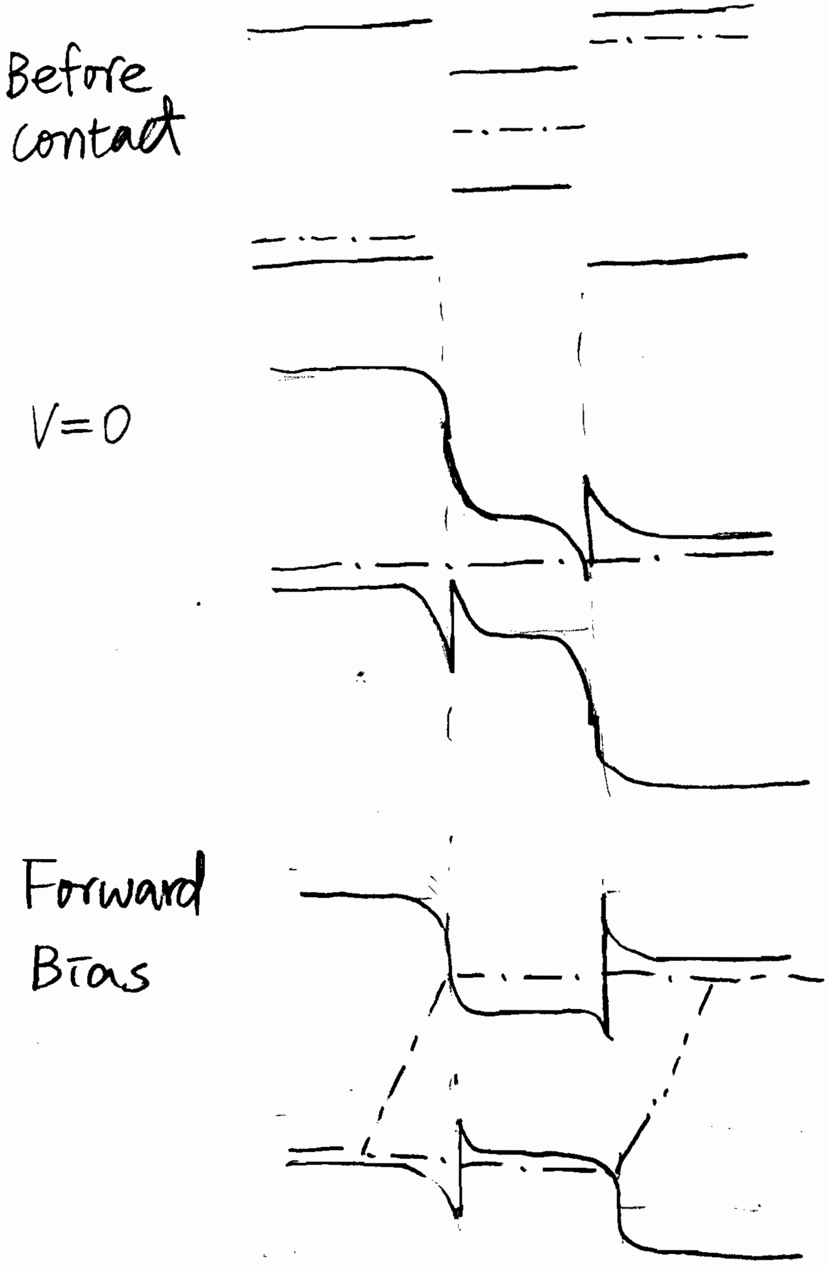
$$\Gamma = \frac{\int_{-\frac{d}{2}}^{\frac{d}{2}} |E(x)|^2 dx}{\int_{-\infty}^{\infty} |E(x)|^2 dx}$$

DH: Flat band



Condition for gain
$\Delta E_F > E_g$

Actual band diagram.



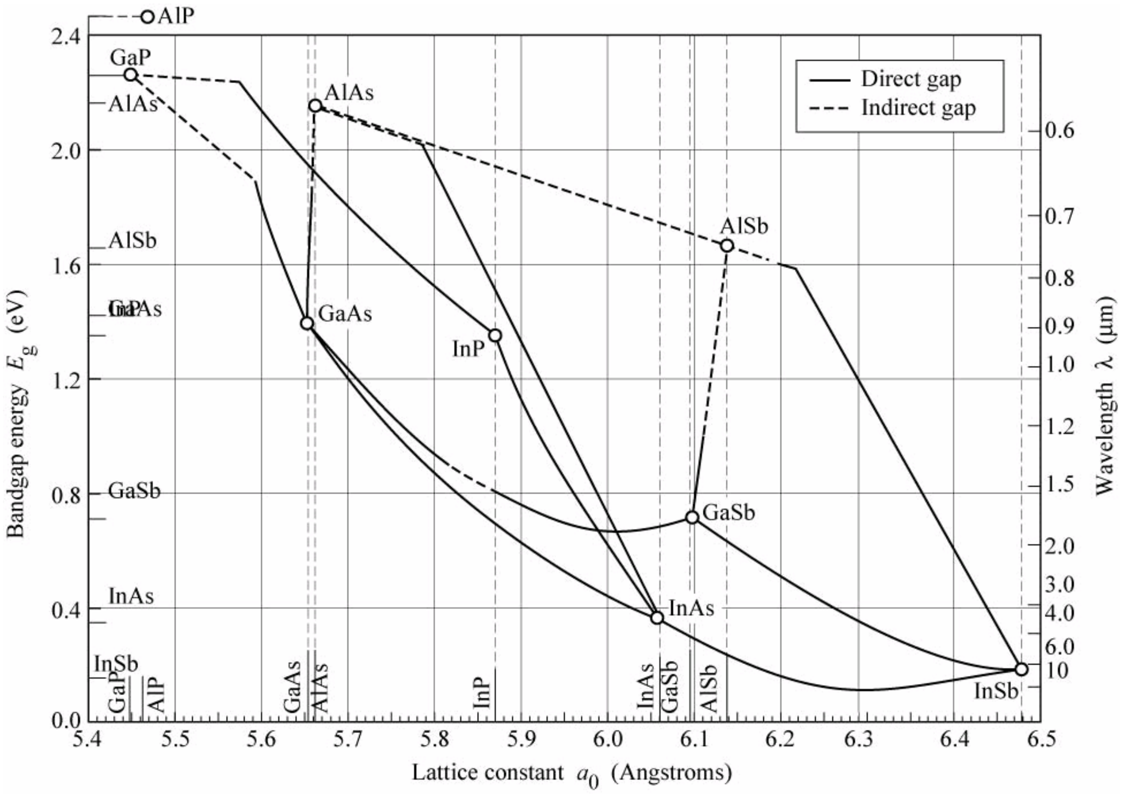


Fig. 12.6. Bandgap energy and lattice constant of various III−V semiconductors at room temperature (adopted from Tien, 1988).

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

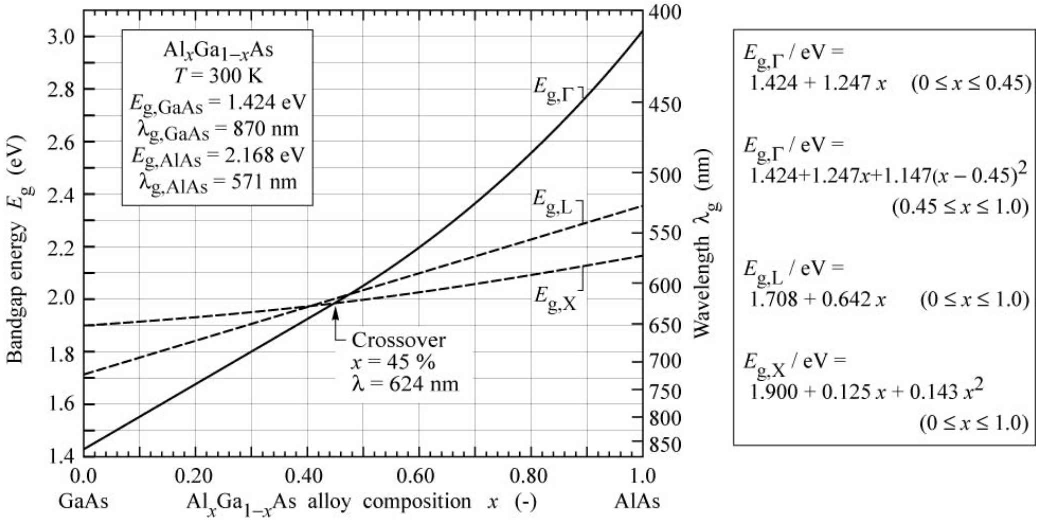
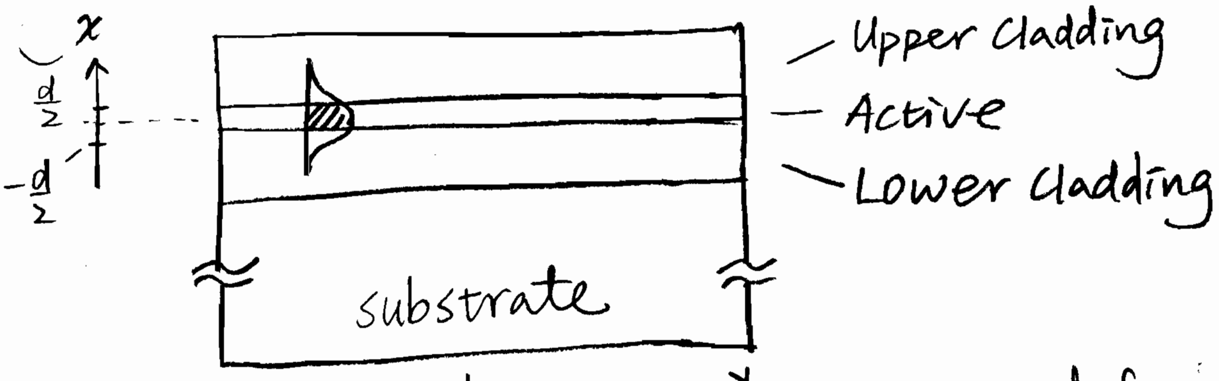
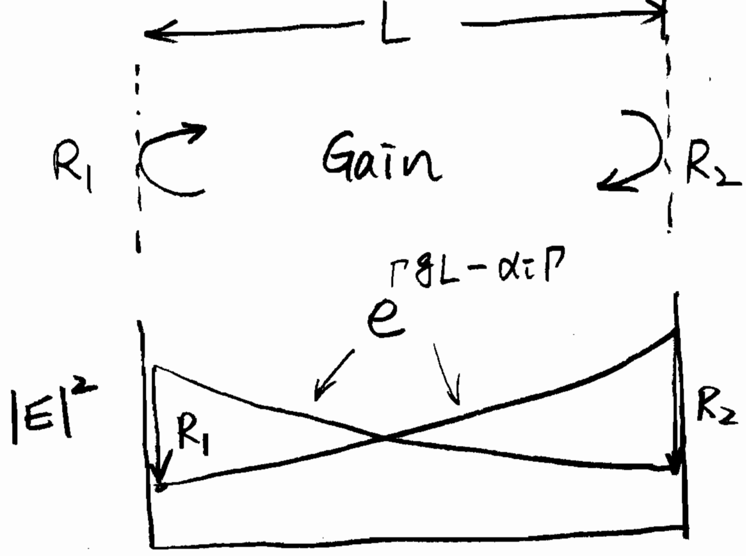


Fig. 12.7. Bandgap energy and emission wavelength of AlGaAs at room temperature. E_Γ denotes the direct gap at the Γ point and E_L and E_X denote the indirect gap at the L and X point of the Brillouin zone, respectively (adopted from Casey and Panish, 1978).

http://www.ecse.rpi.edu/~schubert/Light-Emitting-Diodes-dot-org/chap12/chap12.htm

DH Laser





Uncoated facet

$$r = \frac{n-1}{n+1} \approx 0.56\,, \quad n \approx 3.5$$

$$R = r^2 = \left(\frac{n-1}{n+1}\right)^2 \approx 31\%$$

Material gain = g

Modal gain = Γg

Confinement factor = Γ

$$\Gamma = \frac{\int_{-d/2}^{d/2} |E(x)|^2 dx}{\int_{-\infty}^{\infty} |E(x)|^2 dx}$$

Threshold Condition

$$e^{(\Gamma g_{th}-\alpha_i)L} \cdot R_2\, e^{(\Gamma g_{th}-\alpha_i)L} \cdot R_1 = 1$$

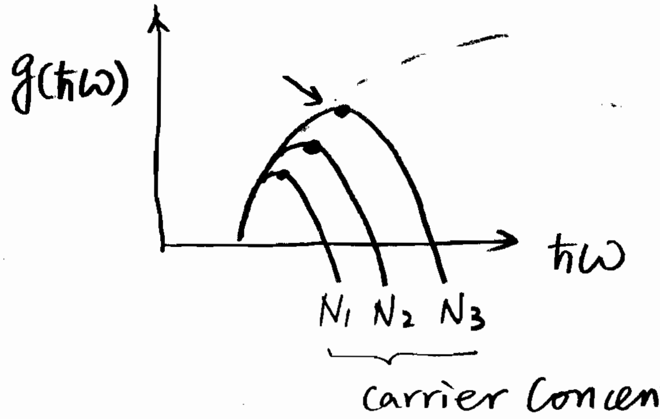
α_i : intrinsic loss

$$R_1 R_2\, e^{2(\Gamma g_{th}-\alpha_i)L} = 1$$

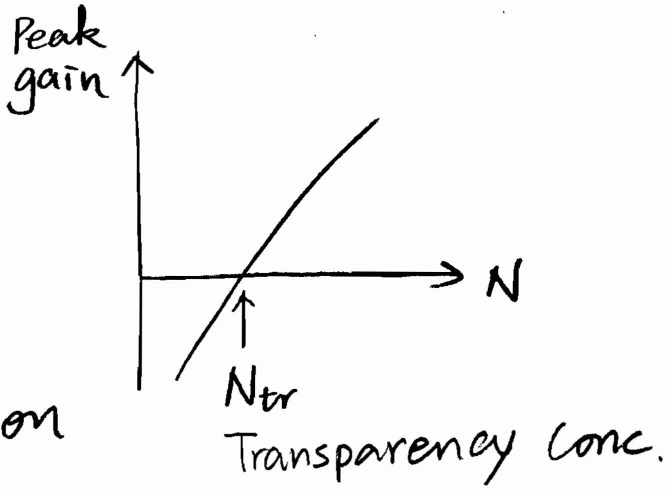
$$\Gamma g_{th} - \alpha_i = \frac{1}{2L} \cdot \ln \frac{1}{R_1 R_2} \equiv \alpha_m$$: distributed mirror loss (cm^{-1})

$$g_{th} = \frac{1}{\Gamma}(\underset{\uparrow \text{ real loss}}{\alpha_i} + \underset{\nwarrow \text{ useful loss (output power)}}{\alpha_m})$$

Linear Gain Approximation



$\Rightarrow$



$$g(N) = a(N - N_{tr})$$

$$g_{th} = g(N_{th}) = a(N_{th} - N_{tr}) = \frac{1}{\Gamma}(\alpha_i + \alpha_m)$$

$$N_{th} = N_{tr} + \frac{1}{\Gamma a}(\alpha_i + \alpha_m)$$

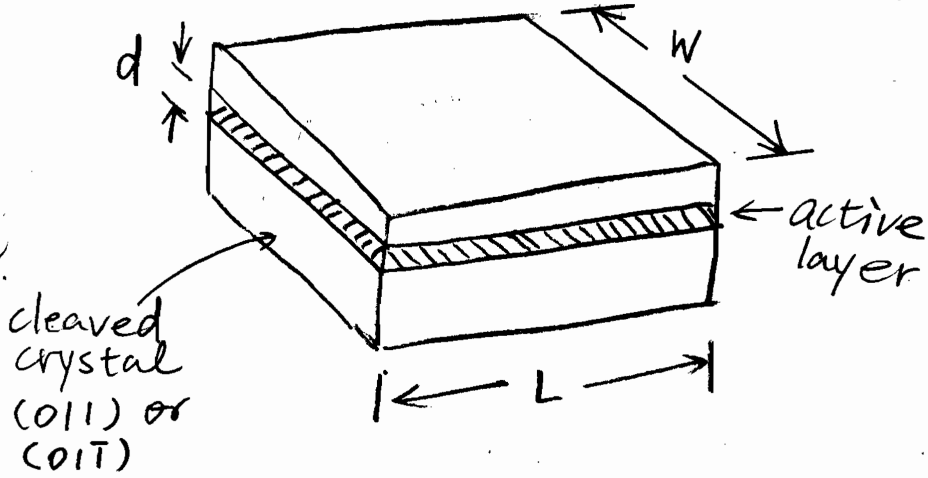
Threshold current density J_{th}

$$J_{th} = \frac{N_{th}}{\tau_e} \cdot q \cdot d$$ ← active layer thickness

τ_e: carrier lifetime

$$I_{th} = J_{th} \cdot W \cdot L$$

$$= \frac{N_{th}}{\tau_e} \cdot q \cdot \underbrace{(d \cdot W \cdot L)}_{\text{active volume}}$$



T_e is usually a function of N also

$$\frac{N}{T_e(N)} = R(N) = A_{nr}N + BN^2 + CN^3$$

↑

Recombination
Rate

$A_{nr}N$: Nonradiative recombination

BN^2 : Spontaneus recomb.

CN^3 = Auger Recomb.

(collision of 2 electrons, knocking 1 electron to VB and the other to higher energy CB)