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

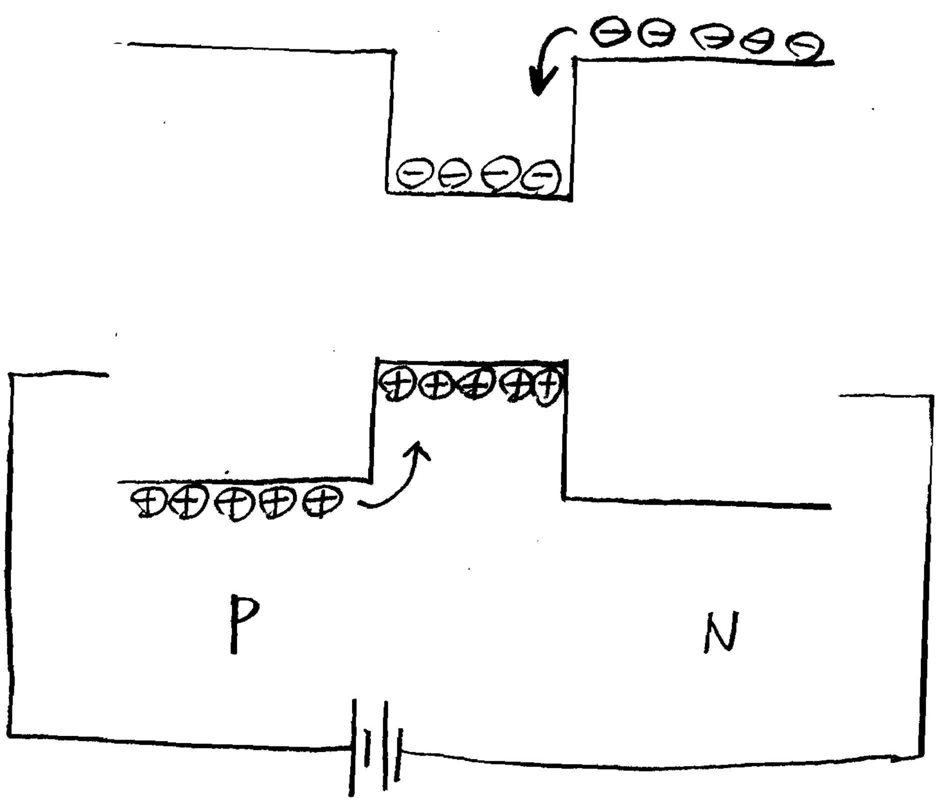
Double Heterostructure laser – 1970

Zh. I. Alferov

Quantum well lasers – late 1970's

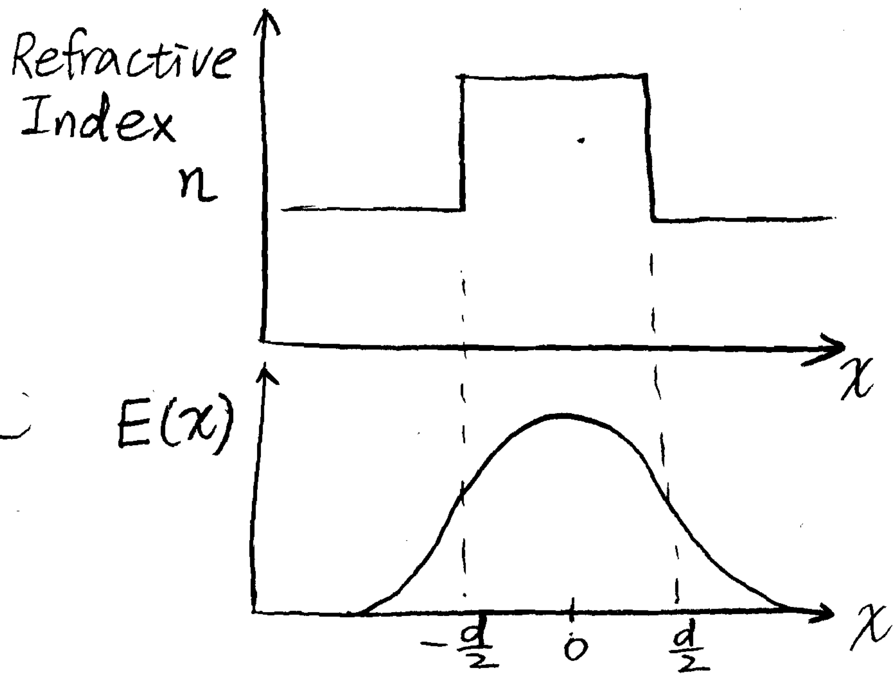
Strained QW lasers – late 1980's

Double Heterostructure (DH)



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

→ Carrier confinement



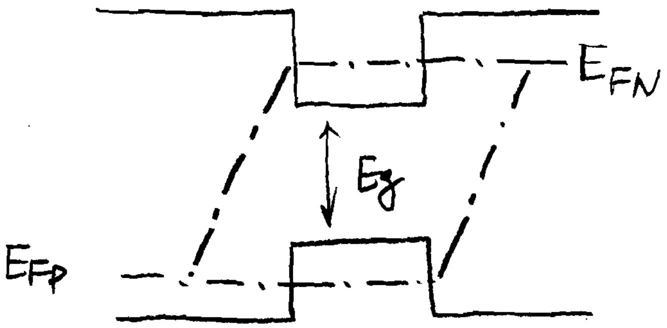
Small bandgap
→ higher n

⇒ Optical confinement

Confinement Factor

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

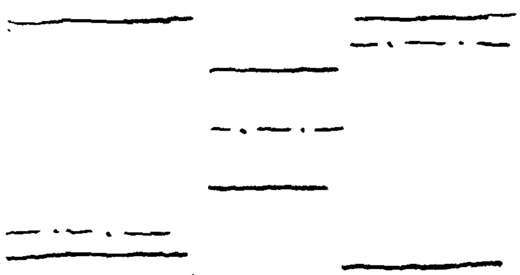
DH: Flat band



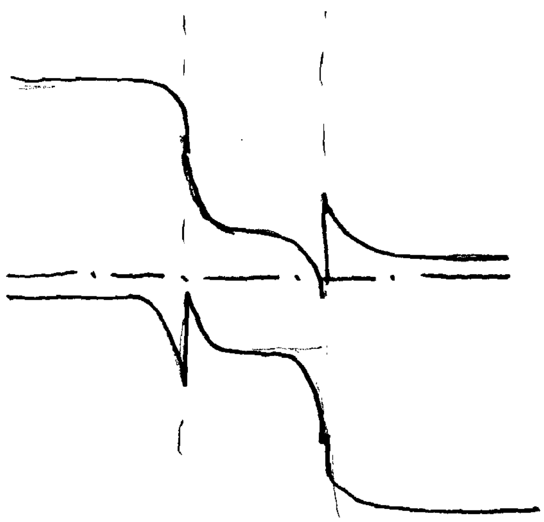
Condition for gain
$\Delta E_F > E_g$

Actual band diagram.

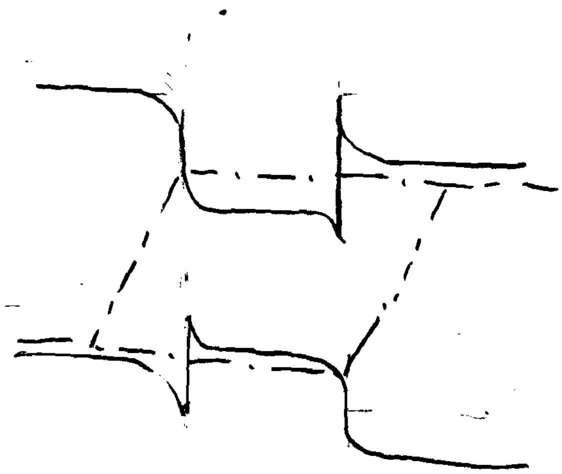
Before contact



V=0



Forward Bias



Properties of $Al_xGa_{1-x}As$

	Unit	GaAs	$Al_xGa_{1-x}As$, $0<x<0.45$
Bandgap Energy	eV	1.424	1.424 + 1.247x
Electron Effective Mass	m_0	0.067	0.067 + 0.083x
Hole Effective Mass	m_0	0.5	0.5 + 0.29x
Dielectric Constant	ε_0	13.1	13.1 – 3x
Conduction Band Discontinuity	%	-	$\Delta E_C \sim 67\% \, \Delta E_g$
Valence Band Discontinuity	%	-	$\Delta E_V \sim 33\% \, \Delta E_g$

Bandgap-vs-Lattice Constant of Common III-V Semiconductors

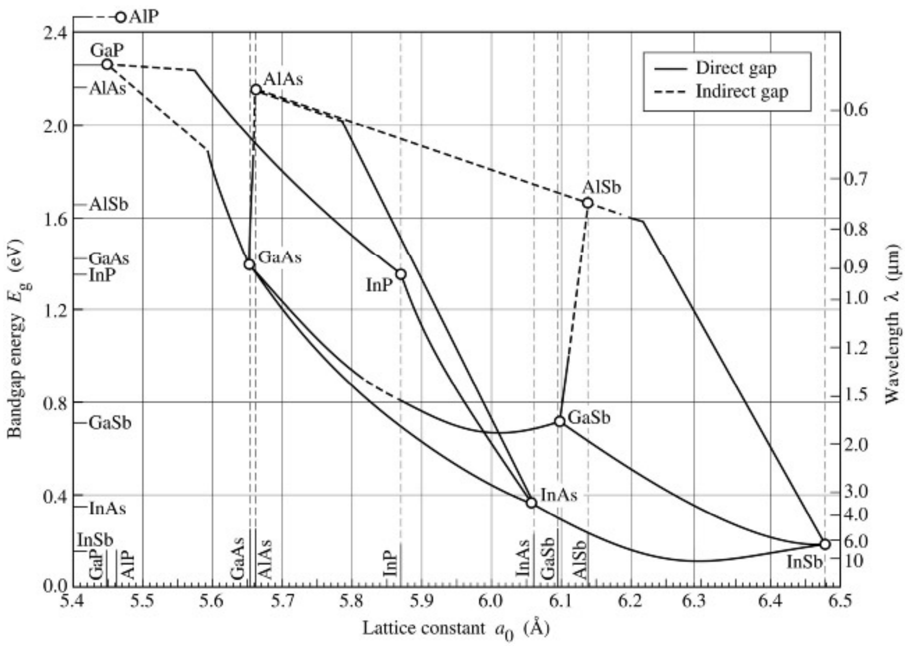


Fig. 7.6. Bandgap energy and lattice constant of various III-V semiconductors at room temperature (adopted from Tien, 1988).

Bandgap Energy of $Al_xGa_{1-x}As$

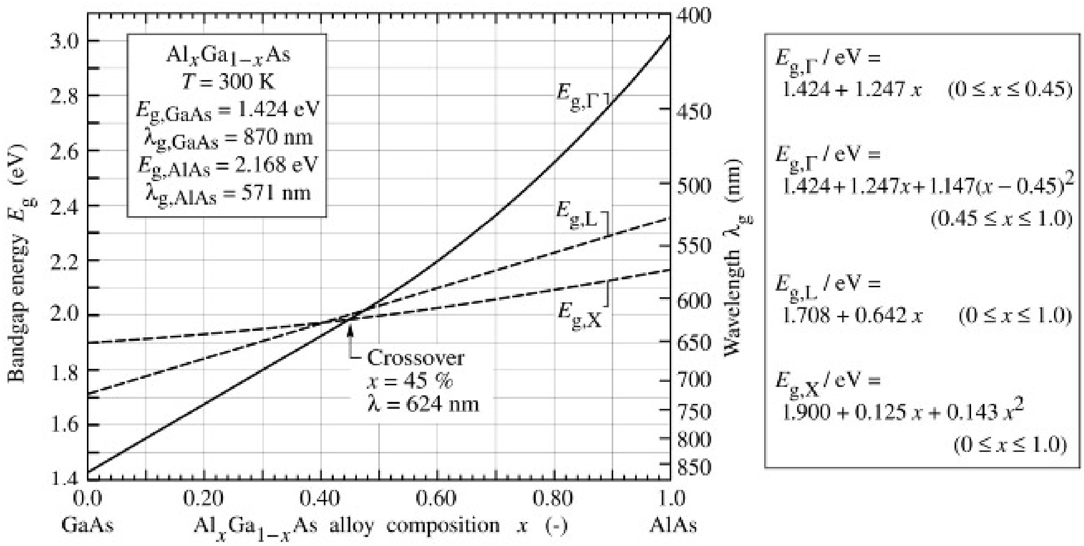


Fig. 7.7. Bandgap energy and emission wavelength of AlGaAs at room temperature. E_Γ denotes the direct gap at the Γ point and E_L and E_X denote the indirect gap at the L and X point of the Brillouin zone, respectively (adopted from Casey and Panish, 1978).

Efficiency Performance for Visible LEDs

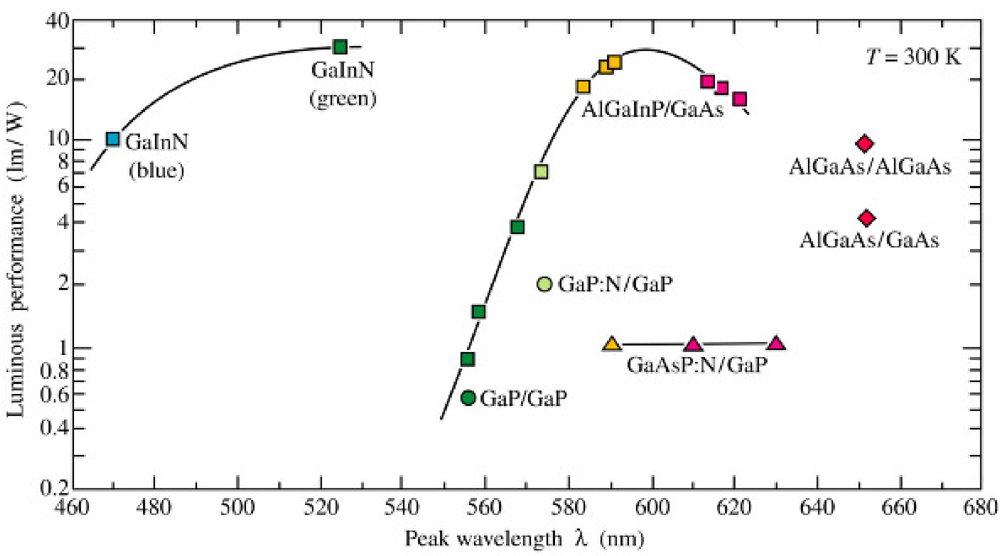


Fig. 7.14. Overview of luminous performance of visible LEDs made from the phosphide, arsenide, and nitride material system (adopted from United Epitaxy Corporation, 1999; updated 2000).

AlGaInP

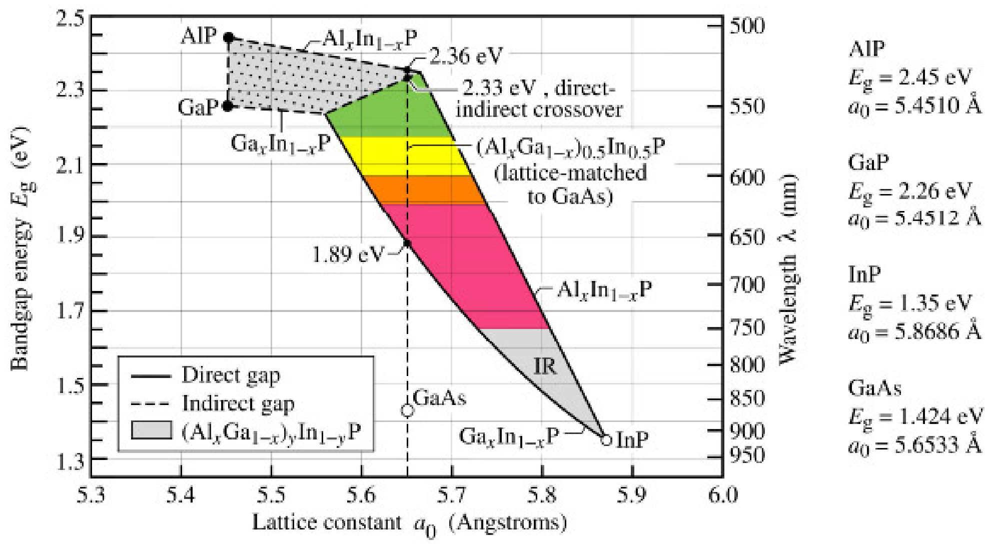


Fig. 7.9. Bandgap energy and corresponding wavelength versus lattice constant of $(Al_xGa_{1-x})_yIn_{1-y}P$ at 300K. The dashed vertical line shows $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ lattice matched to GaAs (adopted from Chen *et al*. 1997).

AlN-GaN-InN

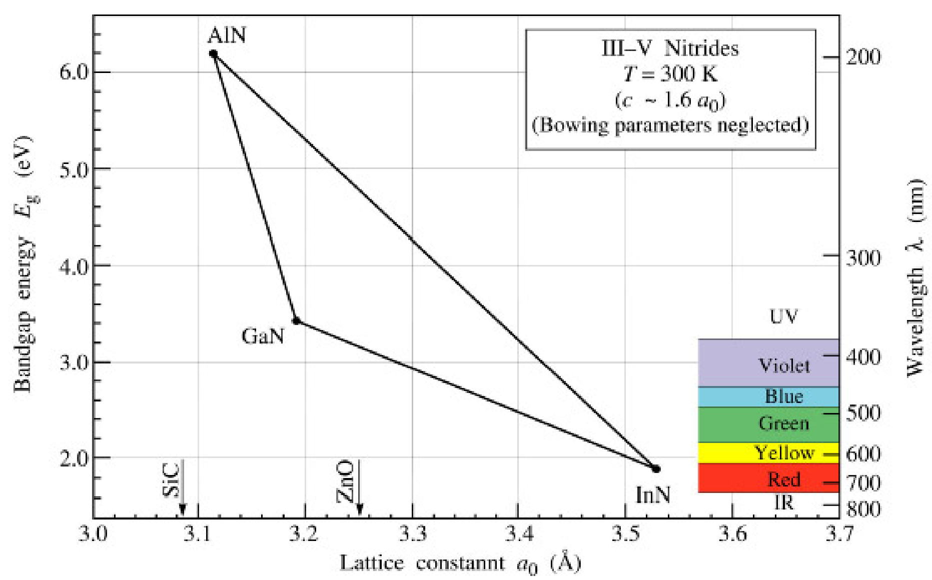
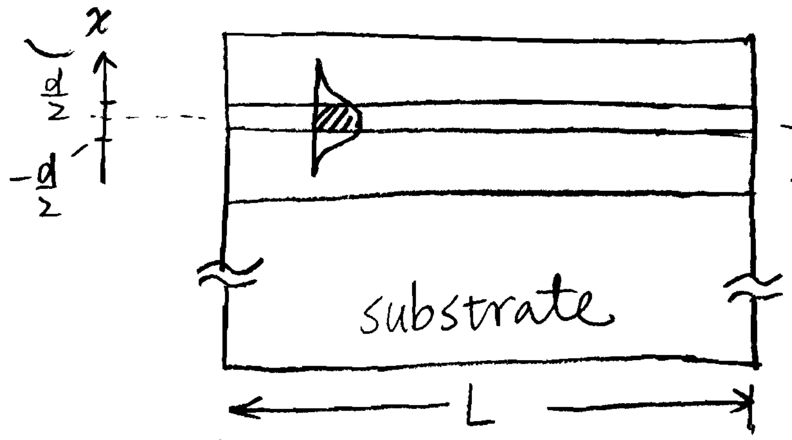


Fig. 7.12. Bandgap energy versus lattice constant of III-V nitride semiconductors at room temperature.

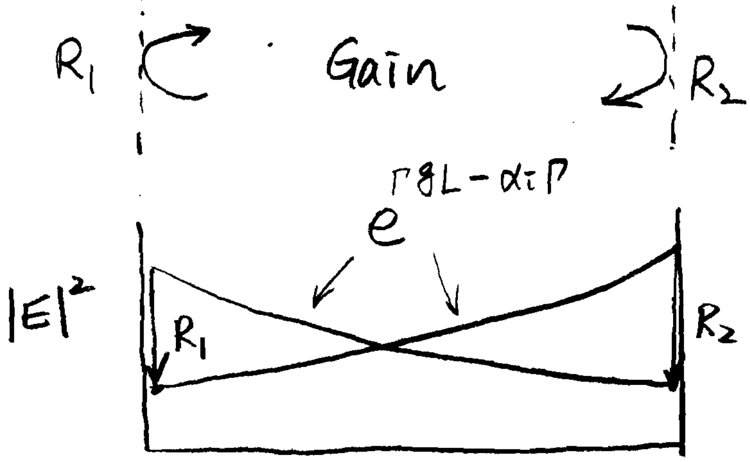
DH Laser



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 $= \Gamma g$

Confinement factor $= \Gamma$

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

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

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

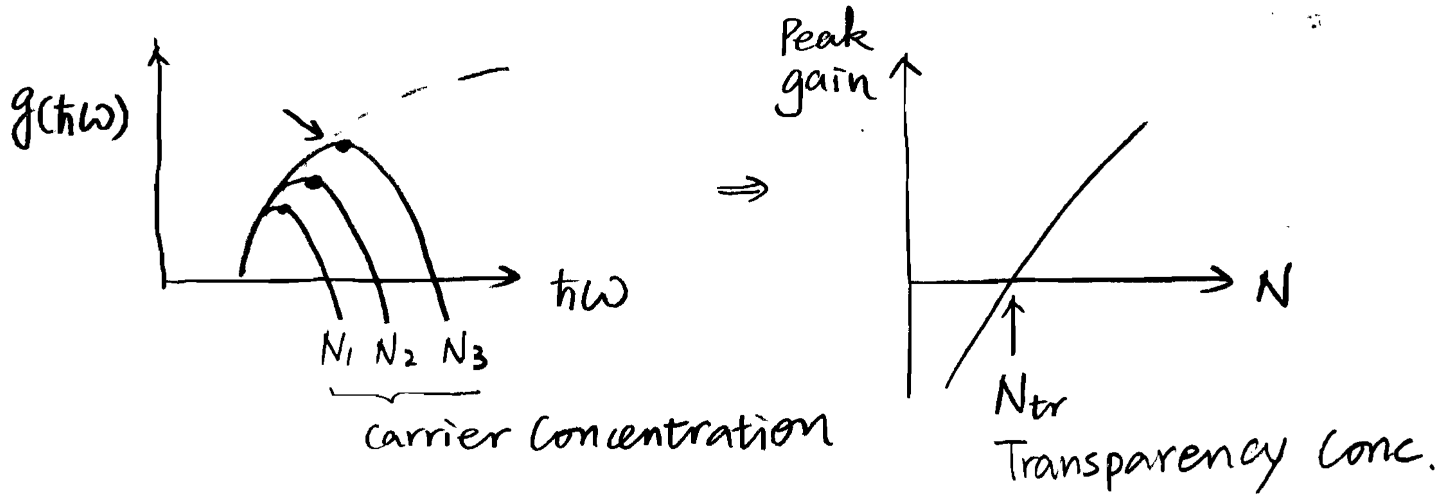
$$\Gamma g_{th} - \alpha_i = \frac{1}{2L} \cdot \ln \frac{1}{R_1 R_2} \equiv \alpha_m$$: distributed mirror loss (cm^{-1})

$$g_{th} = \frac{1}{\Gamma} (\alpha_i + \alpha_m)$$

α_i ↑ real loss

α_m ↖ useful loss (output power)

Linear Gain Approximation



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

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

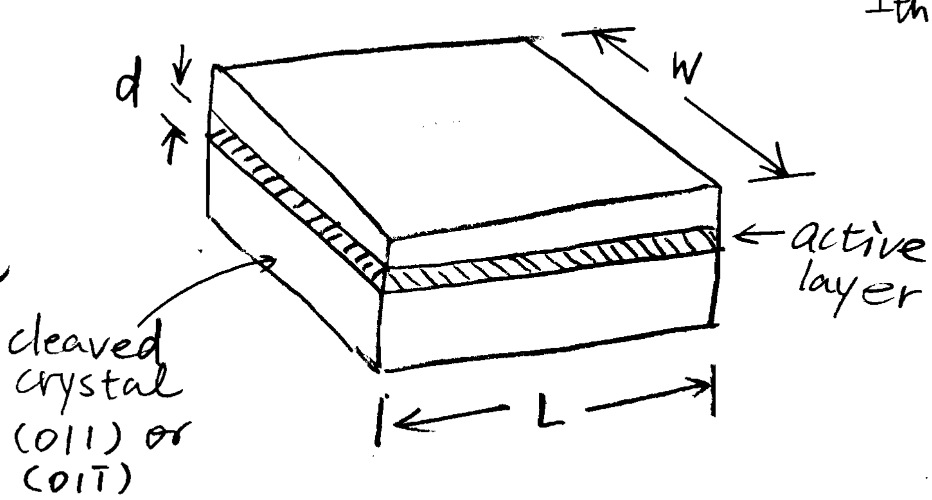
$$N_{th} = N_{tr} + \frac{1}{\Gamma a}(\alpha_i + \alpha_m)$$

Threshold current density J_{th}

$$J_{th} = \frac{N_{th}}{\tau_e} \cdot q \cdot d$$

← active layer thickness (d)

τ_e: carrier lifetime



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

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

τ_e is usually a function of N also

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

↑ Recombination Rate

$A_{nr}N$: Nonradiative recombination

BN^2 : Spontaneous recomb.

CN^3 : Auger Recomb.
(collision of 2 electrons, knocking 1 electron to VB and the other to higher energy CB)