Phys 4061 – Lecture Twelve – LEDs and Laser Diodes

Radiative Recombination can be considered as being analogous to spontaneous emission in 2 level atoms.

Wavelength of emission is determined by the bandgap E_g

$$\lambda_{max} = \frac{c}{\nu_{min}} = \frac{hc}{E_g}$$

- $\lambda_{max} = 10^4$ Å for semiconductors like Si and Ge.

LEDs are based on radiative recombination from a forward biased junction.
Require appropriate junctions for visible radiation.

- eg:
    - GaAs (λ_{max} ~8000 Å)
    - lower melting point than Si facilitates doping
    - direct bandgap material

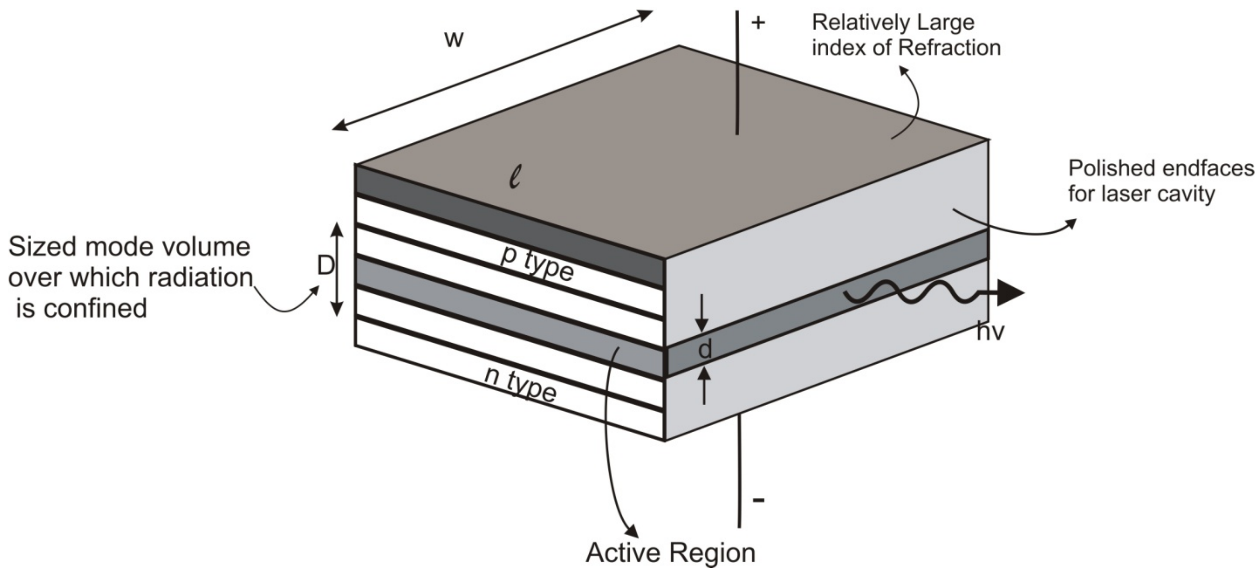
Optical losses from LEDs are due to total internal reflection since the refractive index is generally large (n~ 3.6 for GaAs).

Enclosing the junction with a clear plastic case reduces total internal reflection.
Here θ_c the critical angle is larger than for diode air interface.
The hemispherical case insures that most rays have $\theta_i < \theta_c$
Most common applications of LEDs include:

- displays
- arrays segmental display, similar to LCD's but even lower power

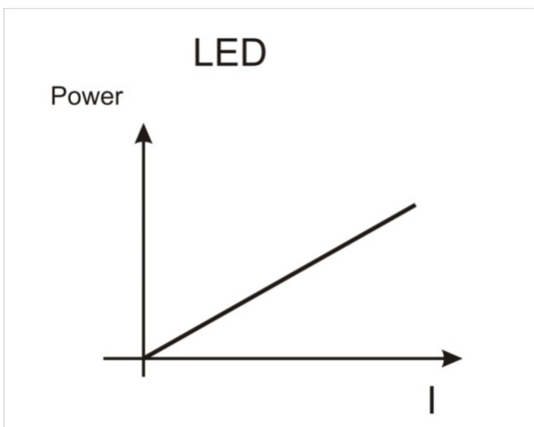
Laser Diodes utilize stimulated radiative recombination

- forward bias junction
- power output depends on current
- populations of electron-hole pairs related to injected electron density

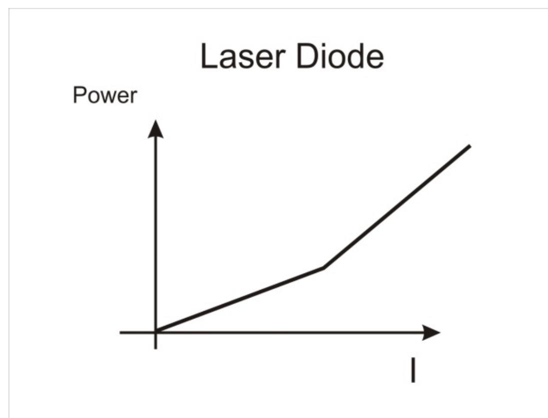


Note:
For Gas Lasers: D < d (previously covered in this course)
Diode Lasers: D > d (mode distribution greater than size of gain medium)

LED vs Laser Diode: Emission Characteristics

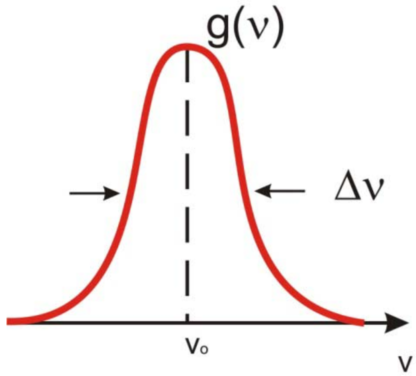


I is the injected current



Angular spread of the beam is reduced	Large angular spread
Highly coherent output	Partially coherent output

Comparison of gain coefficients of laser diode and gas laser



Line shape is generally Lorentzian due to homogenous broadening from lattice interactions.
$g_{max} = 2/\pi\Delta\nu$ where $\Delta\nu$ is the FWHM.
Recall the Lineshape in gas lasers is Gaussian

$$\gamma = ((n_2 - n_1)\ A\ g(\nu) / 8\pi)(\lambda^2/n_i^2)$$

where n_2 and n_1 represent densities in the CB and VB respectively. System is similar to 2 level system used earlier in the context of dilute atomic vapours.

- n_i is the index
- n_2 is the density of injected electrons in CB
- Assume $n_1 \sim 0$
- A (analogous to A_{21}) is the rate of recombination

$$\gamma_t = \alpha + \left(\frac{1}{2L}\right)\ln\left(\frac{1}{R_1R_2}\right)$$

- α is losses per unit length and R_1 and R_2 are reflectivites of polished diode endfaces

$$\gamma(\nu = \nu_o) = \gamma_t \text{ gain limited by peak value of } g(\nu)$$

For Diode Laser

$$n_{2\text{Threshold}} = \frac{8\pi^2 n_i^2 \Delta\nu \left[\alpha + \left(\frac{1}{2L}\right)\ln\left(\frac{1}{R_1R_2}\right)\right]}{2\lambda^2 A}$$

- n_i is sufficiently large for reflection and feedback
- sometimes end faces are AR coated

Define: J => current density

The rate of injection of electrons per unit volume is J/qd

The loss rate (including recombination) is R_ℓ

$J/qd = R_\ell n_2$ (Steady State)

– Radiation confinement is actually within mode volume determined by D.

$J/qD = R_\ell n_2$

$$J_t = \frac{8\pi^2 n_i^2 \Delta\nu}{2\lambda^2} (Dq) \left(\frac{R_\ell}{A}\right) [\alpha + \left(\frac{1}{2L}\right) \ln\left(\frac{1}{R_1 R_2}\right)]$$

Example: For GaAs

Given the values below, what is $\Delta\nu$?

$A/R_l \sim 1$ (nearly unit quantum efficiency)
$\alpha \sim 10/cm$
$D \sim 2\mu m$
$\ell \sim 500\ \mu m$

From $\Delta\nu$, find J_t and since $\ell w = (500 \times 250)\ \mu m^2$, find the threshold current $\ell w J_t$.

Compare this estimate with laser diode operating current.