Semiconductor lasers [read Svelto 9.4]

- forward biased p-n diode
  - active area \( \approx 20 \mu m \times 250 \mu m \times 1 \mu m \)
  - typical current \( \approx 15 \) mA
  - current density \( \approx 300 - 1000 \) A/cm\(^2\)
  - typ. voltage \( \approx 2 \) V
  - input power \( \approx 30 \) mW

\[ \lambda : \]
- AlGaAs/GaAs \( - 720 - 850 \) nm
- InGaAsP/InP \( - 1.15 - 1.67 \) \( \mu m \)
- InGaAs/GaAs \( - 900 - 1100 \) nm
- InGaP/InGaAlP/GaAs \( - 630 - 750 \) nm
- InGaN/sapphire \( - 405 - 450 \) nm
How to achieve inversion

**p-n junction**

![Diagram of p-n junction with heavily doped p and heavily doped n regions.](image)

**Equilibrium**

\[ E_c \]

**Holes**

\[ E_v \]

**Electrons**

\[ F_n = F_p \]

**Junction space-charge region**

→ **Depleted**

**Forward bias**

![Diagram showing forward bias with increased carrier concentration in the active region.](image)

**Carrier concentration controlled by carrier diffusion**
Homojunction laser threshold high because carriers spread out by diffusion - larger volume ⇒ lower carrier density

→ Double Heterostructure Laser

Confine carriers using heterostructure techniques.

\[ \text{p-AlGaAs} \quad \text{GaAs} \quad \text{n-AlGaAs} \]

\[ \Delta E_c \]

\[ \Delta E_v \]

\[ \sim 0.15 \mu m \]

- Carriers build up and confined in the GaAs layer
- Thickness is only \( \sim 0.15 \mu m \). For same current density, carrier density is increased \( \times 6 \) compared to \( 1 \mu m \) diffusion thickness
- Much lower threshold current - room temp cw operation possible

\[ \text{In}_{x} \text{Ga}_{1-x} \text{As}_{y} \text{P}_{1-y} \] can be lattice matched to \[ \text{InP} \] for the right \( x/y \) ratio: Bandgap of alloy is lower than \[ \text{InP} \] gap - so the active region is \[ \text{InGaAsP} \].

- Active region also has higher index of refraction:
  \[ n = 3.2 \] (GaAs)
  \[ 3.4 \] (AlGaAs)
  so light is guided in the active layer
Quantum Well lasers.

- Insert one or more quantum wells into the active region.
- Modified DOS increases gain as discussed earlier in semester.

Band diagram

Step-index

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- Graded index QW laser

Graded composition-confined region
- **Distributed Feedback (DFB) laser**

  need for single mode lasers:
  - For high speed communication lasers ≥ 1 GHz
  - Fiber dispersion causes pulse broadening
  - Need to limit the bandwidth
  - DFB laser gives single mode selection

  Simple Fabry-Perot GaAs laser, L = 250 µm

  mode spacing:

  Typical laser gain bandwidth ≈ 6 meV

  → ~10 modes oscillate

  Introduce a periodic index variation along the laser gain length

  This gives a resonant Bragg reflection for

  \[ \Delta \beta = 2 n_{eff} \Lambda \]

  → enhance feedback for selected wavelength
  - Single mode operation
  - need short period Λ

  This is done by building and burying a corrugation structure into the laser

  ![Diagrame](image)
- Vertical cavity surface emitting laser (VCSEL)

  * Similar to the semiconductor Fabry-Perot saturable absorber structure

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GaAs - AlAs multilayer reflector n-doped

GaAs - AlAs multilayer reflector p-doped

InGaAs - QW active layer

GaAs - 10-20 Um

GaAs - substrate
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Current flows in vertical direction.
Structure is etched to 20 Um circular diameter

Can be built into arrays