Fabrication of Semiconductor Laser

Rupa Bhaumik

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Light Amplification by the Stimulated Emission of Radiation

A laser is a device in which the light emitted arises from stimulated emission.

Semiconductor laser

- Small size and high speed direct modulation
- High-efficiency

Uses

- Communication
- Surgery
- Optical Recording

Recent Developments

Long distance optical communication : These lasers operate at long wavelengths where optical fiber transmission losses are low

Semiconductor Laser Physics

To understand how a semiconductor laser works:

- Condition under which semiconductor will emit stimulated emission
- Resonance condition for amplification

In a light amplifier : Stimulated emission rate > Absorption rate

$$f_2(1 - f_1) > f_1(1 - f_2) \quad => \quad f_2 > f_1$$

where f_1 and f_2 are non-equilibrium distribution functions defining occupancy of conduction and valence bands.

Using the **Quasi Fermi Levels** for these distribution functions we have,

$$q\,(\varphi_2 - \varphi_1) > E_2 - E_1$$

where φ_1 and φ_2 : Quasi fermi levels
E_1 and E_2: Photon emission energy

A laser can be envisioned as a cavity bounded on either side by two mirrors.

$$r_1 r_2 e^{-2\tau L} = 1$$

where r_1 and r_2 : reflectivities
τ : complex number
L : cavity length

Homojunction and Single Heterojunction Lasers

p-n homo-junction formed in crystalline blocks of **GaAs** or **GaP_xAl_{1-x}**

Typical sizes of active region: 1000 Å thick, 10 µm wide and 250 µm long

Lasing Action :

- Forward Bias ≈ Band Gap Potential
- Current is above threshold current $\mathbf{I_{th}}$

Now, $\mathbf{I_{th}} = f$(active region thickness)

So, to decrease the thickness the carrier flow is blocked with a layer of material that has a higher band gap energy than the active region.

The resulting structure is a **single heterostructure**, with active region thickness ~ 0.1 µm

<u>**Disadvantages**:</u> Spectral and spatial output characteristics are relatively unstable.

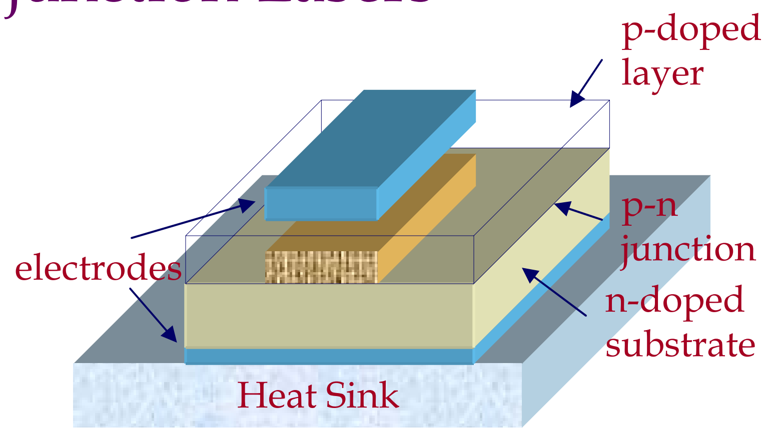


Fig 1. p-n homojunction

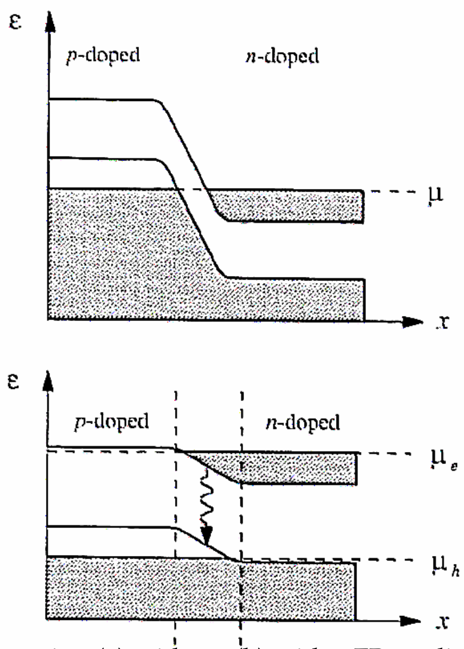


Fig 2. Electron energy and occupation perpendicular to the p-n junction (a) without (b) with a FB applied voltage

Acknowledgment : Semiconductor Laser Fundamentals, Chow and Koch

Double Heterojunction Laser

Sandwich of **$Ga_{1-x}Al_xAs$-GaAs- $Ga_{1-x}Al_xAs$**

Provides both carrier and optical confinement within the active region with a subsequent decrease in threshold current density.

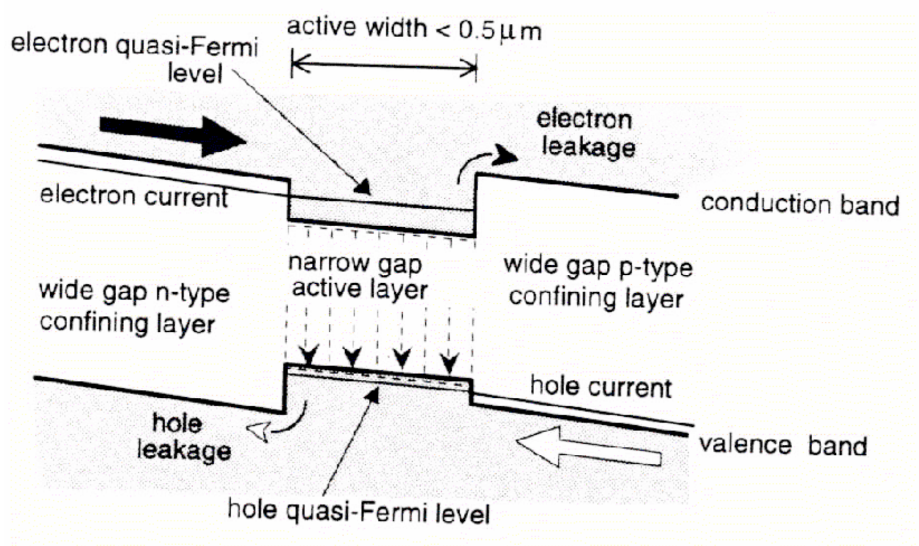


Fig 4. Double Heterojunction (band gap)

Acknowledgement : DFB Semiconductor Lasers, Caroll Whiteaway and Plumb

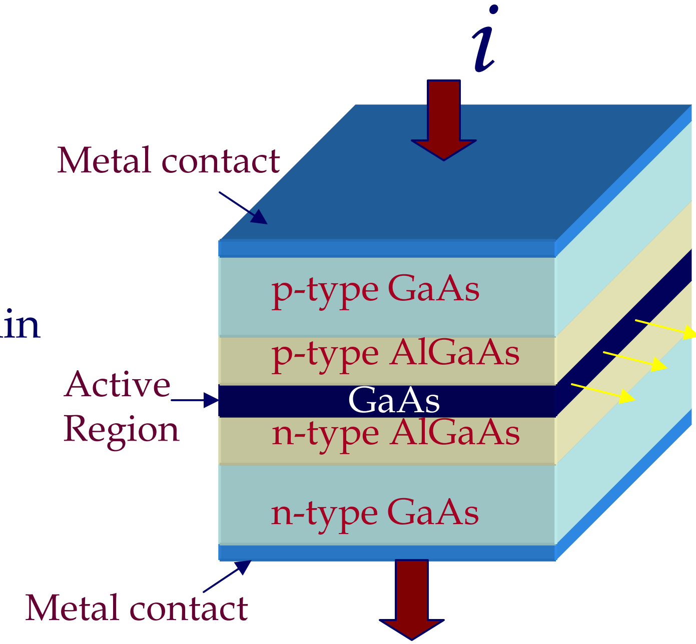


Fig 3. Double Heterojunction (schematic)

Electron and hole leakage currents over the heterobarriers are usually negligible at room temperature so it can operate continuously at room temperature.

Crystal Materials

Most important factor is whether injected carriers can change into light with a reasonably high frequency. We require materials capable for producing various semiconductor lasers with a wide range of lasing wavelength . Injected electron and hole concentration should be higher than approximately 10^{18} cm^{-3}.
Compound Semiconductors, especially III - V compound semiconductors are well suited for this purpose.

Near Infra Red region: GaAlAs / GaAs

Most attractive feature: High speed electron devices can be combined with optical devices monolithically.

Visible Laser Emission: $Ga_{1-x}Al_xAs$

For optoelectronic devices, visible lasers with short wavelengths are convenient. If x content in Al is increased, oscillations with short wavelengths are obtained.

1 μm and longer emission wavelength:

$Ga_xIn_{1-x}As_yP_{1-y}(InP)$, $(Ga_{1-x}Al_x)_yIn_{1-y}As(InP)$, etc

Long wavelengths would have smaller loss.

Crystal Growth Technologies

Substrate quality requirements:

- Crystal direction
- Etch pitch density
- Impurity concentration
- Substrate thickness
- Wafer size

Popular dopants:

	n-type	p-type
GaAs	Si	Zn
InP	S, Sn	Zn

Bulk Growth Techniques:

- Horizontal Bridgeman
- Czochralski

Heteroepitaxial Techniques:

- Liquid Phase Epitaxy
- Vapor Phase Epitaxy / Carbon Vapor Deposition
- Metalo-Organic CVD
- Molecular Beam Epitaxy
- Chemical Beam Epitaxy

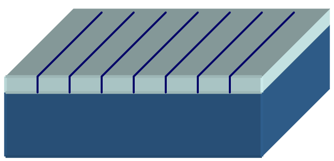
Fabrication of Fundamental Laser Devices

Process:
- Wafer growth
- Waveguide and resonator formation
- Electrode formation process

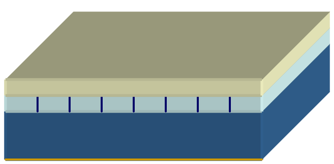
Broad contact laser: Broad electrode structure

(a) Substrate

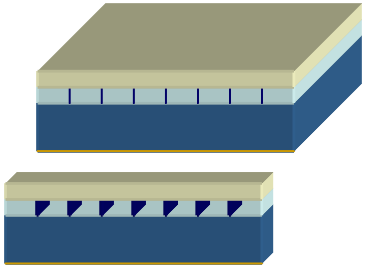
(b) Crystal Growth



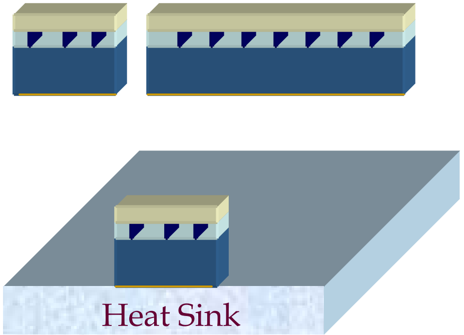
(c) Stripe or Wave Guide structure formation



(d) Substrate is ground to 80 – 100 μm and an electrode is fixed to both sides of the substrate



(e) Cleaving



(f) Cutting and Bonding

Development of Semiconductor Laser

Dev Stage	Time Period	Laser Type	Main Concepts
I	1962 - 1969	GaAs Homojunction	Direct Modulation
II	1970 – 1976	GaAs double HJ	Transverse mode control
III	1977 – 1984	1 µm GaInAlP group	DSM Operation
IV	1984 – 1990	Short Wavelength	Low noise
V	1990 →	Wide Spectral Range	Quantum well, coherence control etc.

Acknowledgment : Process Technology for Semiconductor Lasers, Iga and Kinoshita

Future Applications

Refractive Surgery : Automated Lamellar Keratoplasty (ALK) and Photorefractive Keratectomy (PRK) in Laser In Situ Keratomileusis(LASIK)

Communications : Single photons used to send information

Thank you