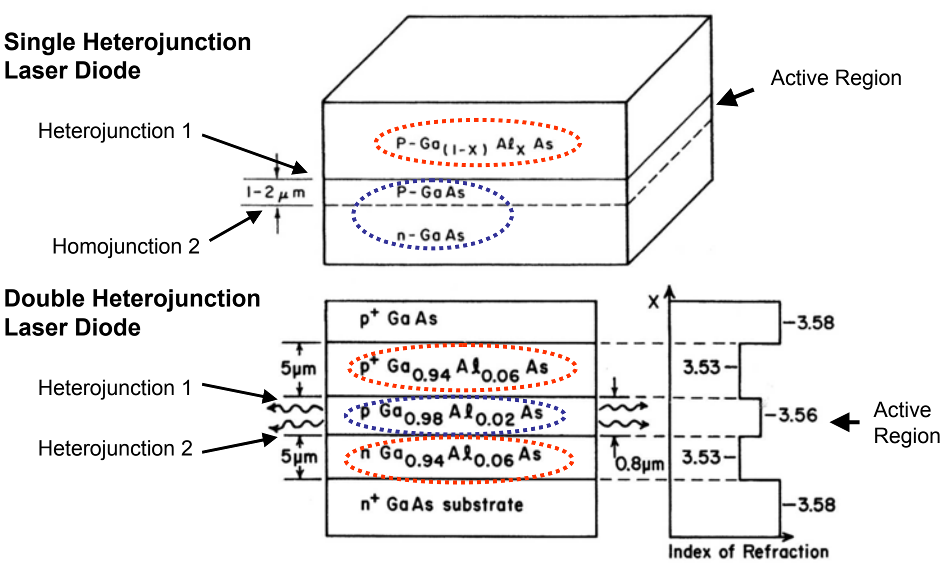
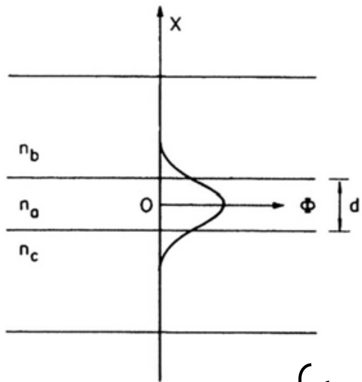
Heterostructure, Confined-Field Lasers

Class: Integrated Photonic Devices
Time: Fri. 8:00am ~ 11:00am.
Classroom: 資電206
Lecturer: Prof. 李明昌(Ming-Chang Lee)

Basic Heterojunction Laser Structures



Optical Field Confinement



In active (guide) region

$$\Phi = A\cos k_a x + B\sin k_a x \quad \textbf{for} \quad -d/2 \le x \le d/2$$

where A and B are constants

In cladding region

$$\Phi = \exp(-k_b x) \quad \textbf{for} \quad x \ge d/2$$

and

$$\Phi = \exp(k_c x) \quad \textbf{for} \quad x \le -d/2$$

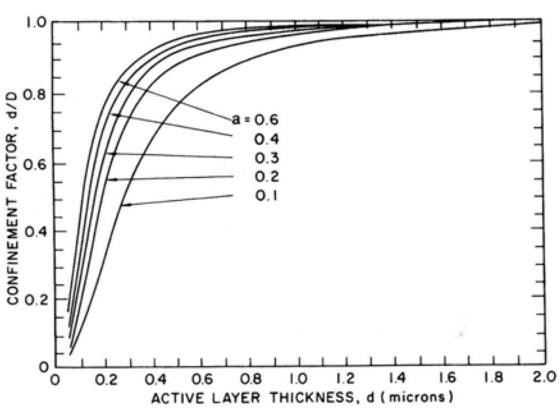
The extinction ratio k_b and k_c can be obtained (by McWhorter's eq.)

$$\begin{cases} k_b = \left(\dfrac{k_0^2 d}{2}\right)\left(\dfrac{n_a^2-\overline{n^2}}{n^2}\right)+\dfrac{1}{2d}\left(\dfrac{n_c^2-n_b^2}{n_a^2-\overline{n^2}}\right) \\ k_c = \left(\dfrac{k_0^2 d}{2}\right)\left(\dfrac{n_a^2-\overline{n^2}}{n^2}\right)+\dfrac{1}{2d}\left(\dfrac{n_b^2-n_c^2}{n_a^2-\overline{n^2}}\right) \end{cases}$$

$$\overline{n^2} = \frac{n_b^2+n_c^2}{2} \qquad k_0 = \frac{2\pi}{\lambda_0}$$

$\longrightarrow$ **find A, B and k_a**

Confinement Factor of The Fundamental Mode in A Symmetry $Ga_{(1-a)}Al_aAs$-GaAs Waveguide



- **Nearly 100% confinement factor can be obtained for active region thickness as small as 0.4 μm**

The confinement factor:

$$\frac{d}{D} = \frac{\int_{-d/2}^{d/2}\Phi dx}{\int_{-\infty}^{\infty}\Phi dx}$$

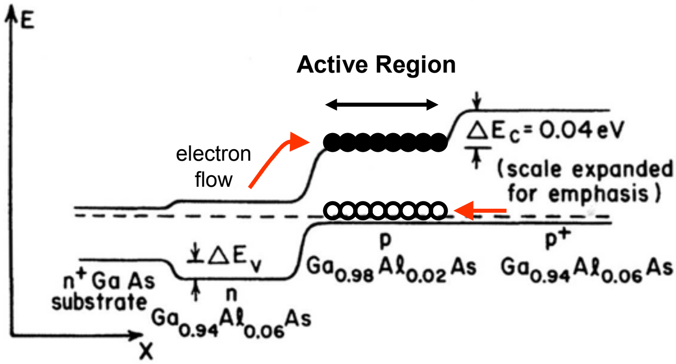
A simple result for a symmetric, three-layer $Ga_{(1-a)}Al_aAs$-GaAs-$Ga_{(1-a)}Al_aAs$ can be expressed by

$$\frac{d}{D} \simeq \frac{\int_0^{d/2} E_0^2\exp(-2\gamma x)dx}{\int_0^{\infty} E_0^2\exp(-2\gamma x)dx}$$

where

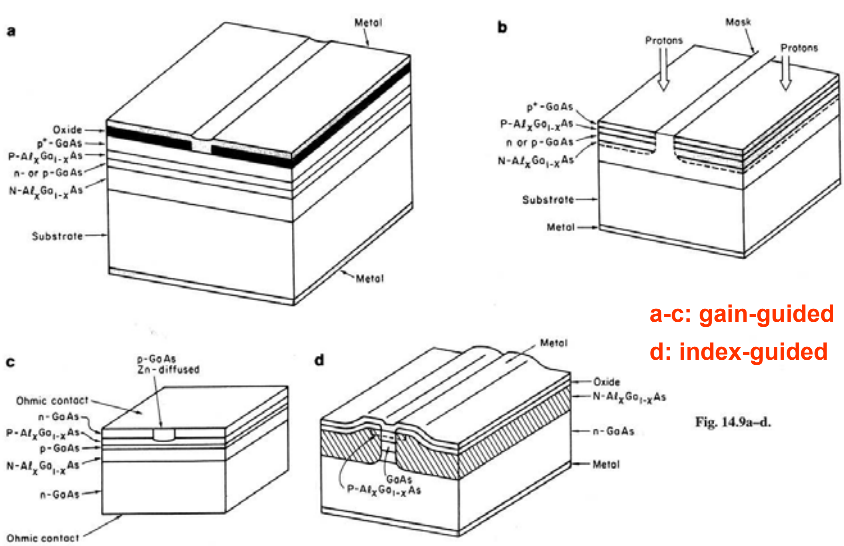
$$\gamma \simeq \frac{(n_a^2-n_c^2)k_0^2 d}{2}$$

Carrier Confinement



- The conduction band discontinuity at the p-p+ interface provides a barrier to the injected electrons
- The valence band discontinuity at the n-p junction prevents hole injection into the n region
- The photons of the optical mode are also confined to the active layer due to high index of refraction

Stripe Geometry Laser

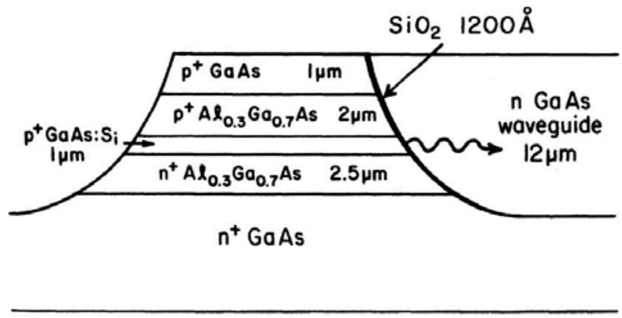


a-c: gain-guided

d: index-guided

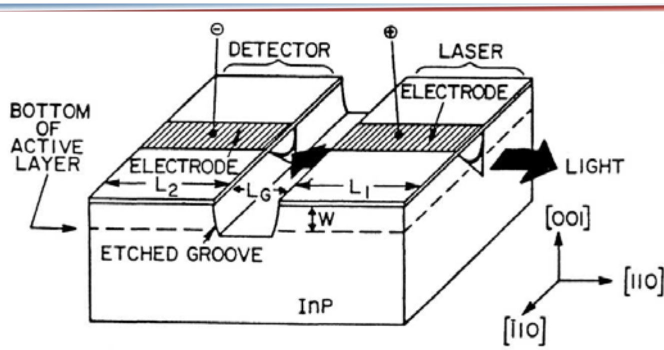
Fig. 14.9a–d.

Integrated Laser Structures



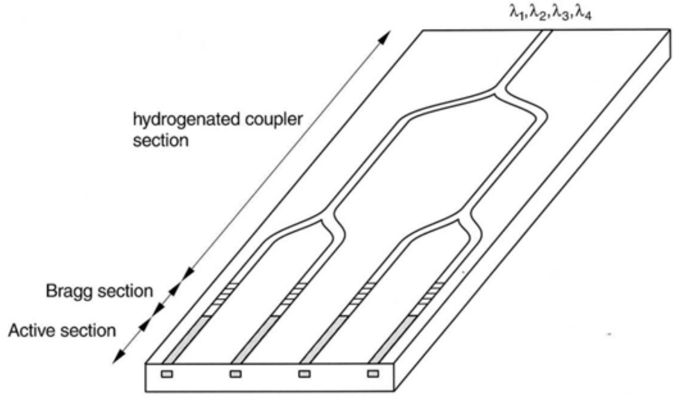
- The active region of the laser is doped with silicon → shift the emission wavelength to 1 um which is transparent to GaAs waveguide
- SiO_2 is coated to provide enough reflection to form Fabry-Perot cavity

Integrated Laser and Monitor photodiode



- Masked chemical anisotropic etching of laser facet to form mirror cavity
- A photodetector is monolithically integrated with the laser to monitor the laser power

Four-Wavelength Selectable OIC Lasers

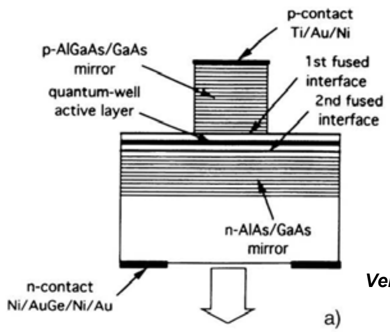


- **Bragg diffraction grating is used for replacing one of the Fabry-Perot mirrors**
- **4 lasers are coupled to a single output by branching waveguides**
- **DFB lasers also provide the advantage of narrower linewidth**

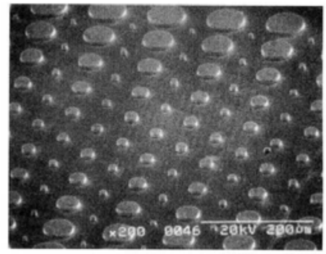
Reliablitiy

- **Catastrophic failure**
  - **High optical power density ~ typically > 3×10^6 W/cm^2**
  - **Due to the presence of grown-in initial defects in the facet surface**
  - **Mechanical damage in the form of pits and protrusions**
  - **Coating the laser facets with a dielectric such as SiO_2, Si_3N_4 is used for reducing the catastrophic damage**
  - **Turn-on transient should be taken care**
- **Gradual degradation**
  - **Aging effect of laser operation**
  - **It results from the formation of defects within the active region that acts as non-radiative recombination centers**
  - **10^6 hr are now being made**

Vertical-cavity surface-emitting lasers (VCSELs)



a)

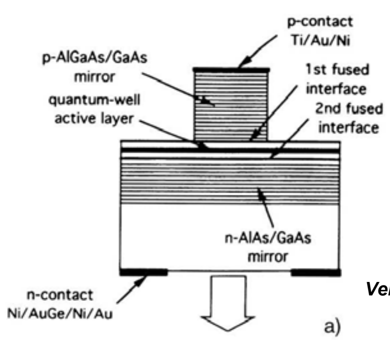


Vertical-cavity surface-emitting lasers (VCSELs)

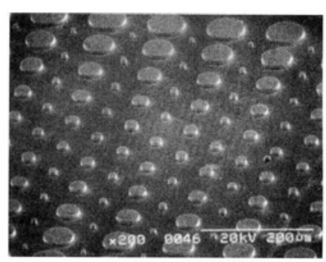
b)

- **Laser emits light through surface rather than through their endfaces**
- **Composition of layers (epitaxial growth)**
  - **Two DFB mirrors**
  - **Active layers --- multilayer, double heterostructures**
  - **A contact window**

Advantage of Vertical-cavity surface-emitting lasers (VCSELs)



a)



Vertical-cavity surface-emitting lasers (VCSELs)

b)

- **Circular emitting window to match the core diameter of an optical fiber to optimize coupling**
- **Arrange in a surface array to couple to a fiber ribbon or bundle --- provide direct chip-to-chip coupling through air**

VCSEL to CMOS Integration