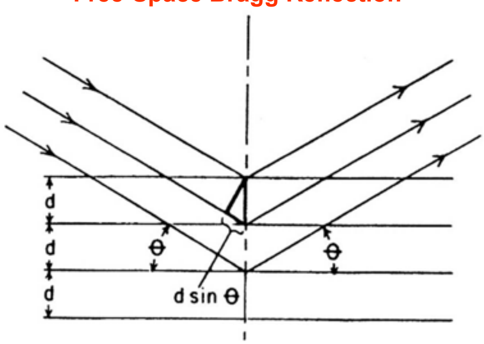
Distributed-Feedback Lasers

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

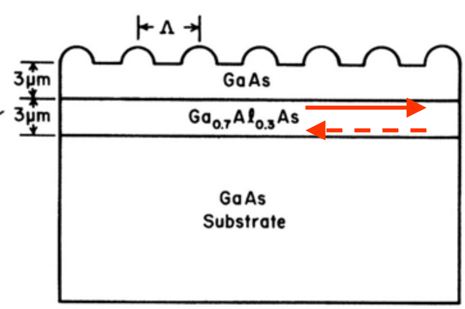
Wavelength Dependence of Bragg Reflections

Free-Space Bragg Reflection



$2d\sin\theta = l\lambda$ **and** $l = 1, 2, 3, \ldots$

Waveguide Bragg Reflection



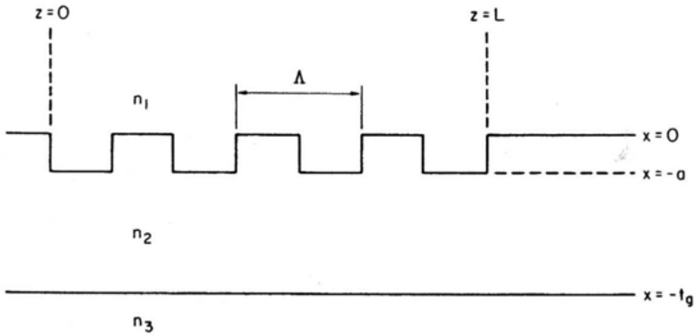
Let θ = 90˚

$2\Lambda = l(\lambda_0 / n_e)$ **and** $l = 1, 2, 3, \ldots$

Effective index

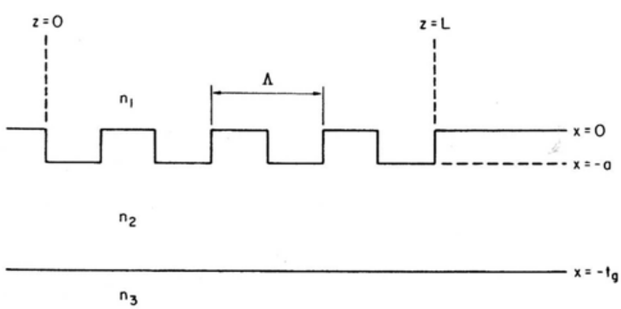
- **Usually only one mode will lie within the gain bandwidth of the laser**

Coupling Efficiency of Wave Reflection



- **The fraction of optical power that is reflected by a grating depends on**
  - **Thickness of the waveguiding layer**
  - **Depth of the grating teeth**
  - **Length of the grating region**

Coupling Efficiency of Wave Reflection



The coupling can be characterized by perturbation assumption

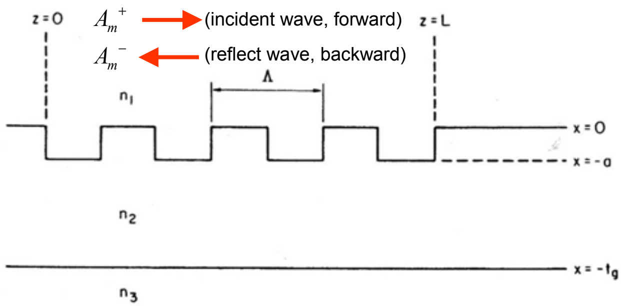
$$\kappa = \frac{2\pi^2}{3l\lambda_0}\frac{\left(n_2^{\,2}-n_1^{\,2}\right)}{n_2}\left(\frac{a}{t_g}\right)^3\left[1+\frac{3(\lambda_0/a)}{2\pi(n_2^{\,2}-n_1^{\,2})^{1/2}}+\frac{3(\lambda_0/a)^2}{4\pi^2(n_2^{\,2}-n_1^{\,2})}\right]$$

where

$$l \simeq \frac{\beta_m\Lambda}{\pi}$$

β_m is the propagation constant of the particular mode m

Coupling Efficiency of Wave Reflection

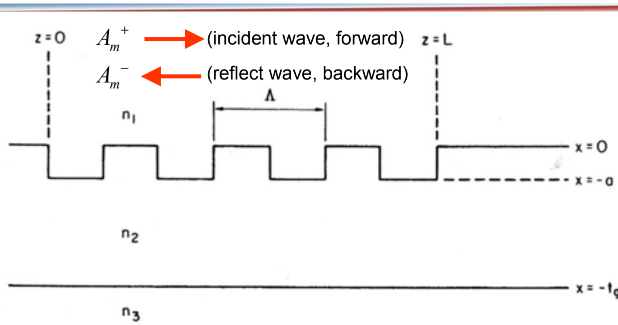


For the first order (l=1) case, the reflection is essential limited to coupling between the forward and backward traveling wave

$$A_m^+(z) = A_m^+(0)\frac{\cosh[\kappa(z-L)]}{\cosh(\kappa L)} \quad \text{and} \quad A_m^-(z) = A_m^+(0)\frac{\kappa}{|\kappa|}\frac{\sinh[\kappa(z-L)]}{\cosh(\kappa L)}$$

L: the length of grating

Coupling Efficiency of Wave Reflection

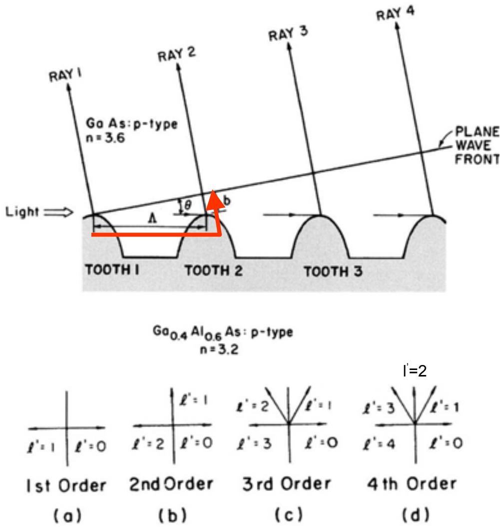


The reflectance and transmittance are

$$R_{eff} = \left|\frac{A_m^-(0)}{A_m^+(0)}\right|^2 \quad \text{and} \quad T_{eff} = \left|\frac{A_m^+(L)}{A_m^+(0)}\right|^2$$

- **The incident power decreases exponentially with z, as power is reflected into the backward travelling wave**

Ray Scattering of Higher-Order Bragg Gratings



For higher-order gratings with periodicity Λ

$$\Lambda = \frac{l\lambda_0}{2n_e} \qquad l > 0$$

The extra path length must be integral multiples of the wavelength to have constructive scattering ray

$$b + \Lambda = \frac{l'\lambda_0}{n_e} \qquad l' = 0, 1, 2, 3, \ldots l$$

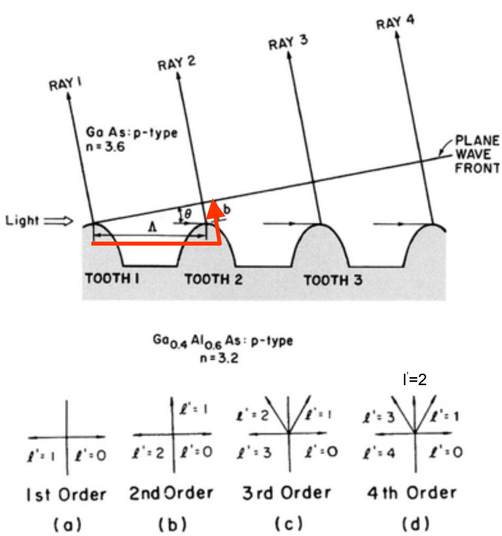
and

$$b = \Lambda \sin\theta$$

Thus,

$$\sin\theta = \frac{l'\lambda_0}{n_e\Lambda} - 1 \qquad l' = 0, 1, 2, 3, \ldots l$$

Ray Scattering of Higher-Order Bragg Gratings



For example of a second-order Bragg grating

$$\Lambda = \frac{\lambda_0}{n_e}$$

Then

$$\sin\theta = l' - 1 \qquad l' = 0, 1, 2$$

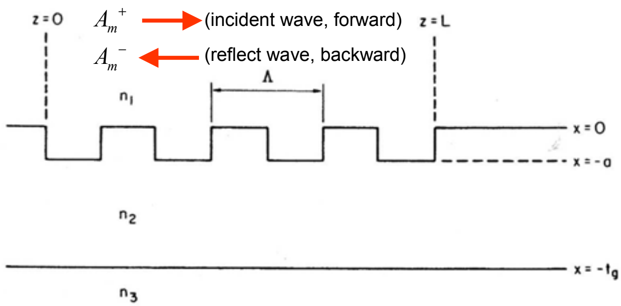
Three diffraction modes

$l' = 0$ →

$l' = 1$ ←

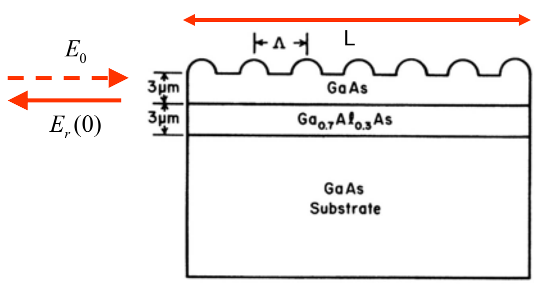
$l' = 2$ ↑

Coupling Efficiency of Wave Reflection



- **Generally, the strong coupling in the transverse direction by second-order Bragg grating is undesirable**
- **A first-order grating is required to yield optimum performance**
- **However, fabrication of the first-order grating is challenging.**

Lasing with Distributed Feedback



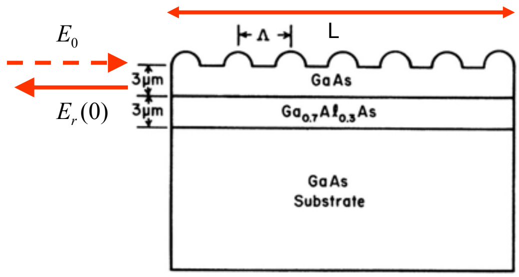
In a gain medium (gain:g),

$$E_r(z) = E_0 \frac{\kappa \exp(j\beta_0 z)\sinh[S(L-z)]}{(g - j\Delta\beta)\sinh(SL) - S\cosh(SL)}$$

where $S^2 \equiv |\kappa|^2 + (g - j\Delta\beta)^2$

The parameter E_0 is the amplitude of a single mode incident on the grating (stimulus)

Lasing with Distributed Feedback



The phase mismatching term,

$\Delta\beta = \beta - \beta_0$ Where β_0 is the propagation constant at the Bragg wavelength

The oscillation condition for the DFB laser corresponds to the case for

$$\frac{E_r(0)}{E_0} \to \infty$$

That is,

$$(g - j\Delta\beta)\sinh(SL) = S\cosh(SL)$$

Lasing with Distributed Feedback

In general, numerical method should be used for exactly solving g and $\Delta\beta$ simultaneously. A special case of solution of lasing frequency

$$\omega_m = \omega_0 - (m + \frac{1}{2})\frac{\pi c}{n_g L} \qquad m = 0, \pm 1, \pm 2, \ldots \qquad \boxed{\Delta\beta \equiv \beta - \beta_0 \simeq \frac{(\omega - \omega_0) n_g}{c}}$$

Supposing that $g >> |\kappa|, \Delta\beta$ **ω_0 : Bragg Frequency**

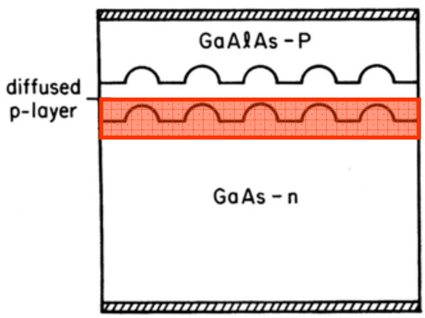
It is interesting to note that no oscillation can occur at exactly the Bragg frequency ω_0. The mode spacing

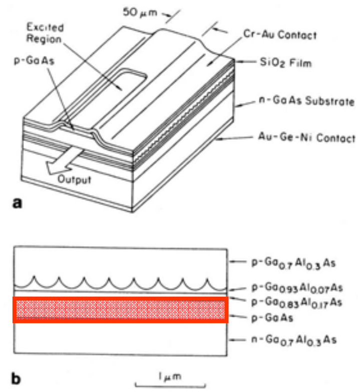
$$\Delta\omega_m \simeq \frac{\pi c}{n_g L}$$

However, only the lasing modes close to the Bragg frequency have the smallest threshold gain. Therefore, in a normal operating condition, the spectral feature of DFB laser often consists of the two longitudinal modes

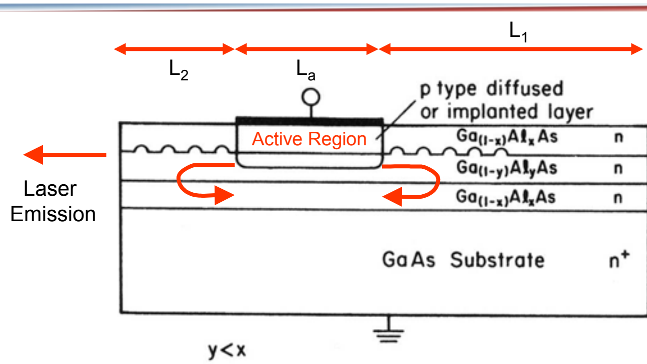
Separate Confinement Heterostructure Lasers

- **Lattice damage is usually created during the grating fabrication. →It is better to separate the active layer out of the grating layer**



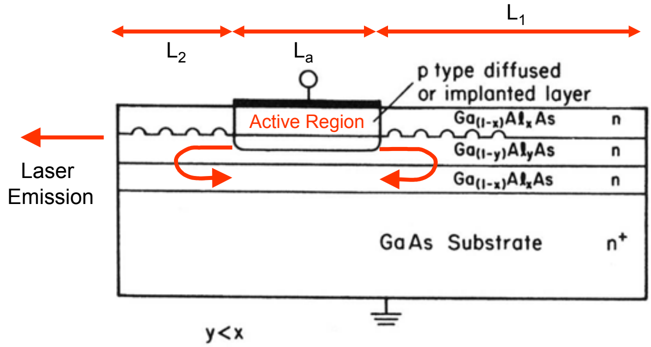


Distributed Bragg Reflection Lasers



- **Two Bragg gratings are employed at both ends of the laser and outside of the electrically-pumped active region**
- **To achieve a single longitudinal mode, one distributed reflector must have narrow bandwidth, high reflectivity at the lasing wavelength**

Distributed Bragg Reflection Lasers



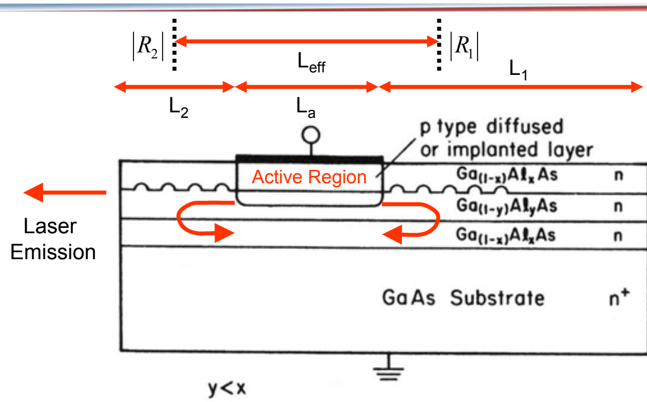
For the passive grating region,

The Transmittivity: $T = \dfrac{\gamma \exp\left[-j(\beta - \Delta\beta)L\right]}{(\alpha + j\Delta\beta)\sinh(\gamma L) + \gamma\cosh(\gamma L)}$ where $\gamma^2 \equiv \kappa^2 + (\alpha + j\Delta\beta)^2$

Loss of grating

The Reflectivity: $R = \dfrac{-j\kappa \sinh(\gamma L)}{(\alpha + j\Delta\beta)\sinh(\gamma L) + \gamma\cosh(\gamma L)}$ (complex)

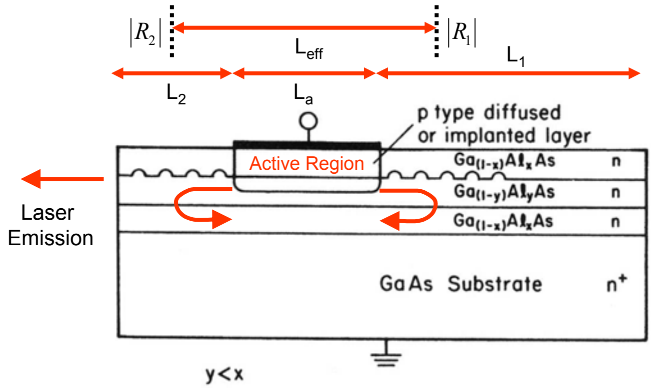
Distributed Bragg Reflection Lasers



Since the reflectivity is complex number, we can consider an effective cavity length

$$L_{eff} = L_a\left(1 + \frac{L_2}{2L_a(\alpha L_1 + 1)} + \frac{1}{2L_a\left(\alpha + \sqrt{\kappa^2 + \alpha^2}\right)}\right)$$

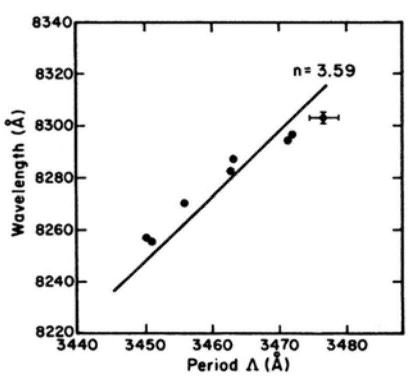
Distributed Bragg Reflection Lasers



The longitudinal mode spacing between the m-th and (m±1)-th lasing mode is approximately

$$\Delta \equiv \left|\beta_m - \beta_{m\pm1}\right| = \frac{\pi}{L_{eff}}$$

Wavelength Selectability



- **Compared with Fabry-Perot lasers, DFB or DBR laser is easy to achieve single-longitudinal-mode operation because the spacing between the m-th and the (m±1)-th mode is generally large and the reflectivity is mode-dependent**