



# **Semiconductor Optical Communication Components and Devices**

## **Lecture 27: Distributed Feedback Diode Lasers**



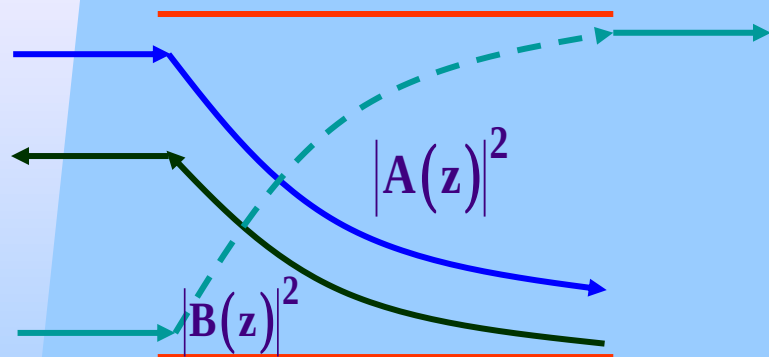
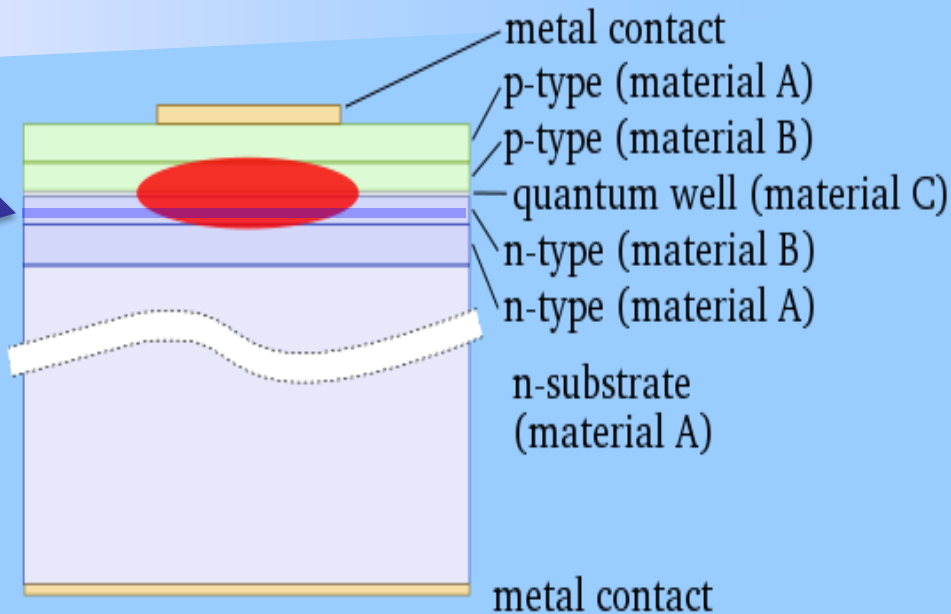
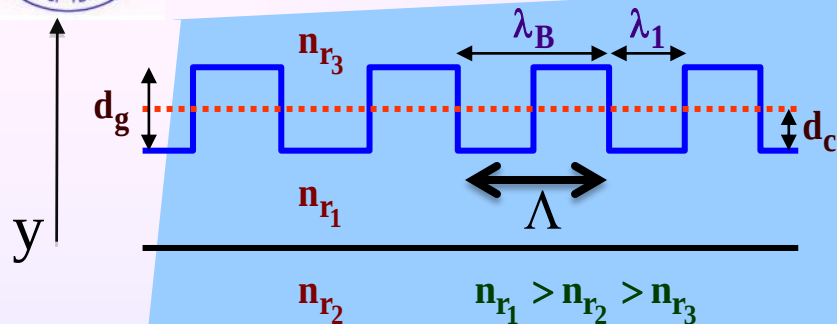
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[http://www.iitk.ac.in/ee/faculty/det\\_resume/utpal.html](http://www.iitk.ac.in/ee/faculty/det_resume/utpal.html)



# Distributed Feedback Laser (DFB Laser) - I



$$\frac{m\pi}{\Lambda} = \beta_s = \frac{\omega}{v} = \frac{2\pi/\lambda_o}{c/n_{\text{eff}}}, \quad \Lambda = \frac{m\lambda_o}{n_{\text{eff}}}$$

$$\kappa \text{ max for } \lambda_1 = \frac{\lambda_B}{2} \quad \lambda_m = \lambda_B \pm \lambda_B^2 \left( m + \frac{1}{2} \right) / 2n_r L$$

$$\kappa = \frac{k_o}{2n_{\text{eff}}} \frac{\int_{-\infty}^{\infty} \Delta E_m(y) \phi^2(y) dy}{\int_{-\infty}^{\infty} \phi^2(y) dy}$$

The modal field as function of x and y is :  $u(x, y) = \psi(x) \phi(y)$

$$\text{and } \kappa = \Gamma_L \kappa_1 - (1 - \Gamma_L) \kappa_2$$

where  $\Gamma_L$  is the lateral confinement



# Distributed Feedback laser (DFB Laser) - II

The effective refractive index is  $n(z) = n_o + \Delta n \cos\left(\frac{2\pi z}{\Lambda} + \psi\right)$

where  $\Lambda$  is the grating period, and the Cos function is the first Fourier component of the rectangular perturbation

$\kappa^2 = k_o^2 n_r^2 - j k_o n_r \alpha$  and  $k_o = \frac{2\pi}{\lambda_o}$  and  $\alpha \ll k_o n_r$  where  $\alpha$  is the loss

The solution of the wave which have the forward and backward propagation is

$$E(z) = R(z)e^{-j\beta_o z} + S(z)e^{j\beta_o z}$$



Backward



Forward

$\therefore -\beta_o + 2q\frac{\pi}{\Lambda} = \beta_o$   $q$  is the number of period required to form  $\Lambda$  with fundamental mode as  $q = 1$

$\kappa^2 \cong \beta^2 - j\alpha\beta + 4\kappa\beta \cos\left(\frac{2\pi z}{\Lambda} + \psi\right)$  where  $\kappa$  is the coupling coefficient and is the measure of the power coupled between the forward and backward wave

where  $\kappa = \frac{k_o \Delta n}{2}$ ,  $\beta = k_o n_o$



# Distributed Feedback laser (DFB Laser) - III

The phase mismatching factor  $\beta$  is given as

$$\delta = \frac{\beta^2 - \beta_0^2}{2\beta_0} \quad \beta - \beta_0 = \Delta\beta \quad \text{any } \Delta\beta \text{ is given by } \Delta\beta = \left( \frac{2n_{eq}}{\lambda_0} - \frac{q}{\Lambda} \right)$$

Where  $q$  is the mode of back scattering and  $\Lambda$  is the period of grating

$$\Delta\beta = 2\pi n_{eq} \left( \frac{1}{\lambda_0} - \frac{1}{\lambda_B} \right) \quad \text{Where } \lambda_B \text{ is the Bragg Wavelength,}$$

where  $\frac{1}{\lambda_B} = \left( \frac{q}{\Lambda} \right)$  If  $q = 1$  then  $\lambda_B = \Lambda$

If  $\alpha$  is the absorption coefficient (Loss)

$$R(z) = r_1 e^{\gamma z} + r_2 e^{-\gamma z}$$

$$S(z) = s_1 e^{\gamma z} + s_2 e^{-\gamma z}$$

$$\text{and } \gamma^2 = \left( \frac{\alpha}{2} + j\delta \right)^2 + \kappa^2$$

The reflection coefficient is given as  $r = \frac{S(0)}{R(0)}$



# Distributed Feedback laser (DFB Laser) - IV

The reflection coefficient is given as  $r = \frac{S(0)}{R(0)}$

$$r = \frac{\gamma \left[ r_0 e^{-j(2\beta_0 L_B + \psi)} \right] \cosh(\gamma L_B) - \left( \frac{\alpha}{2} + j\delta \right) r_0 e^{-j(2\beta_0 L_B + \psi)} + j\kappa e^{j\psi} \sinh[\gamma(z - L_B)]}{\gamma \cosh(\gamma L_B) + \left[ \left( \frac{\alpha}{2} + j\delta \right) + \lambda_0 \kappa r_0 e^{-j(2\beta_0 L_B + \psi)} \right] \sinh(\gamma L_B) e^{j\psi}}$$

$r$  can be expressed as  $r = |r| e^{-j\phi}$

The reflectance is given as

$$R = |r|^2 = \frac{\kappa^2 |\tanh(\gamma L_B)|^2}{|\gamma|^2 + \left\{ \left( \frac{\alpha}{2} \right)^2 + \delta^2 \right\} |\tanh(\gamma L_B)|^2 + 2 \operatorname{Re} \left[ \left( \frac{\alpha}{2} + \delta \right) r^* \tanh(\gamma L_B) \right]}$$

At  $\beta = \beta_0 = (q\pi / \Lambda)$  i.e., the Bragg condition is satisfied, then

$$R_0 = \tanh^2(\kappa L_B)$$



# Distributed Feedback laser (DFB Laser) - V

$$\Delta\delta \cdot L_B \Rightarrow \Delta\lambda_{osc}$$

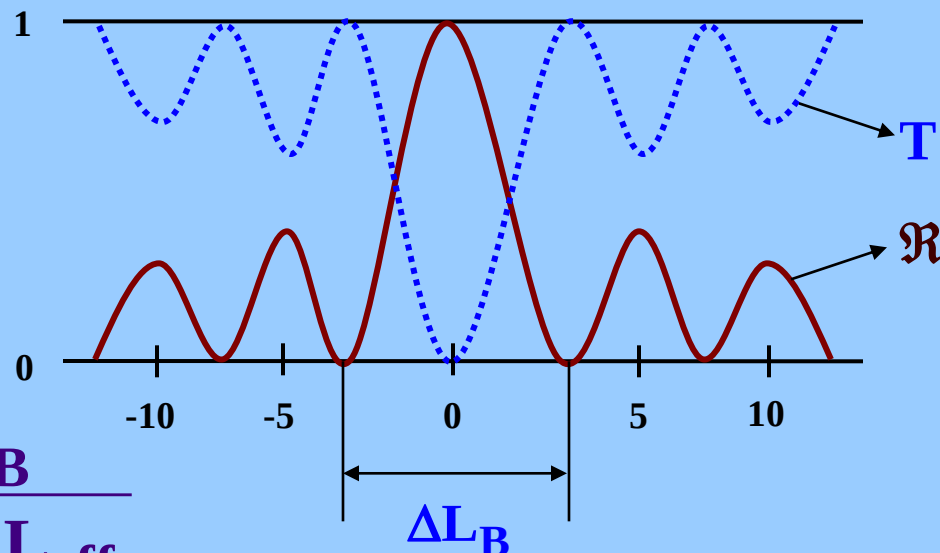
$\Delta L_B$  is a function of  $\lambda$

now

$$\frac{\Delta\lambda}{\lambda_B} = \frac{\lambda_B / n_{eff}}{\left[ 1 + \left( \frac{\kappa L_B}{\pi} \right)^2 \right]} = \frac{\lambda_B}{2n_{eff} L_{eff}}$$

$$\Delta\lambda = \frac{\lambda_B^2}{2n_{eff} L_{eff}}$$

$L_{eff}$  is the effective length of the grating



After introducing grating



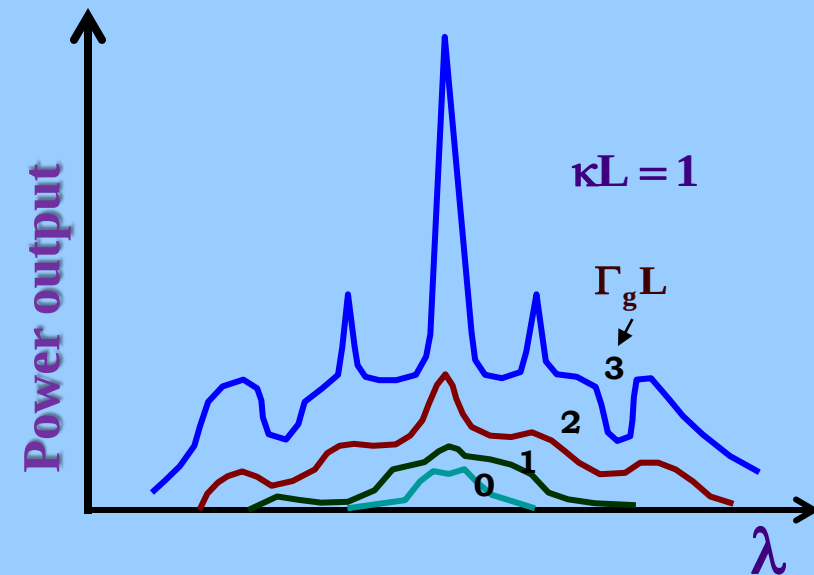
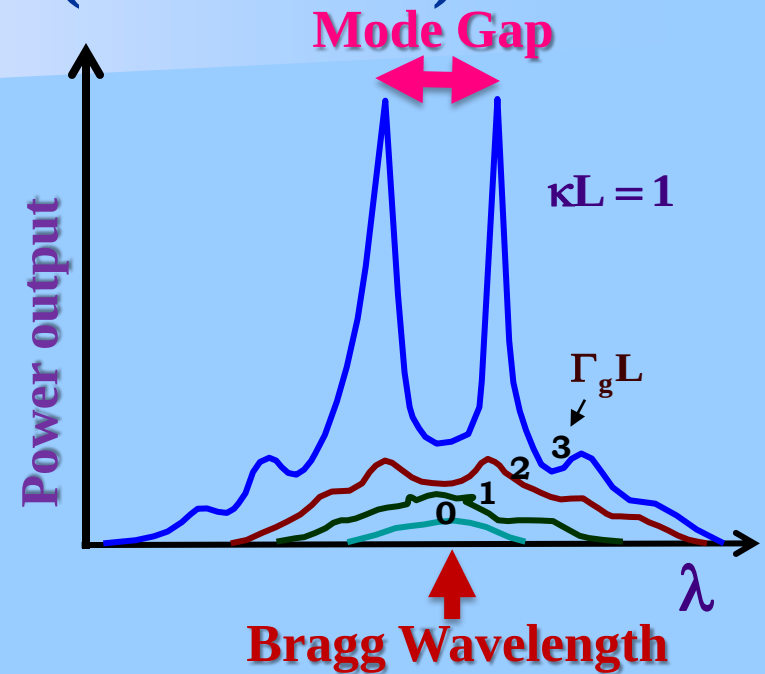
# Distributed Feedback Laser (DFB Laser) - VI

In conventional DFB lasers two equivalent standing waves exist (+1, -1 modes) when there are no facet reflectivities. One of the two are usually selected depending on the corrugation phase at the cavity facets as the relative strength of the mode depends on it. Mathematically it can be shown that because of the above no mode exists at the Bragg wavelength. In simple terms the two reflectors, one at the left and the other at the right are not clearly identified by the wave and hence two peaks. However if the two reflectors are identified by one half being a mirror reflection of the other half then the two mirrors are clearly identified as shown below. Then one peak is obtained at the Bragg wavelength, with some satellite peaks. Main peak linewidth  $\sim 10$ s of MHz

$\kappa$  max for  $\lambda_1 = \frac{\lambda_B}{2}$   $\pi/4$  phase slip



Phase slip =  $\Delta L = \frac{\Lambda}{2} = \frac{d_g}{2} = \frac{\pi}{4}$





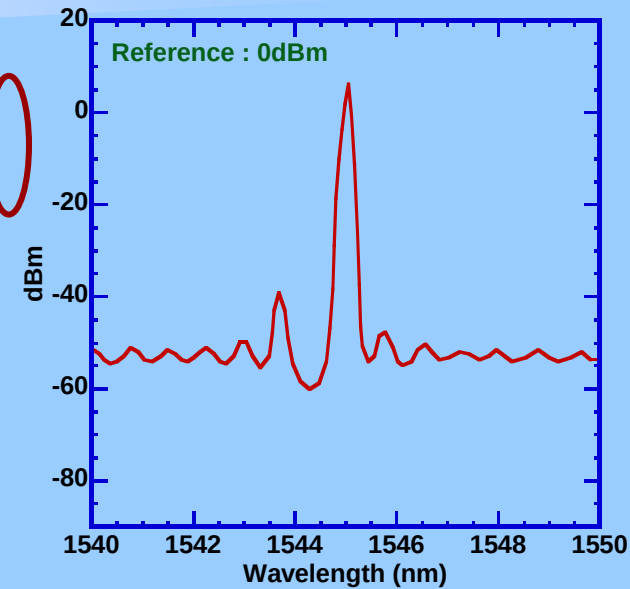
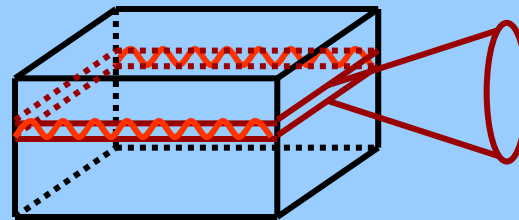
# Distributed Feedback Laser (DFB Laser)

**Distributed Feedback Corrugation**

**Top Metal Contact**

$p^+$

$n^+$



**Oxide insulator layer**

**Barrier layer**

**Active layer**

**dBm is**

$$10 \cdot \log(P_{\text{out}}/1\text{mW})$$

**Light Output**

**InGaAsP Barrier (10nm)**



**Active layer**

**InGaAsP Quantum Well (5nm)**

**Strained-Layer Multiple-Quantum-Well Structure**

**N-InP Substrate**

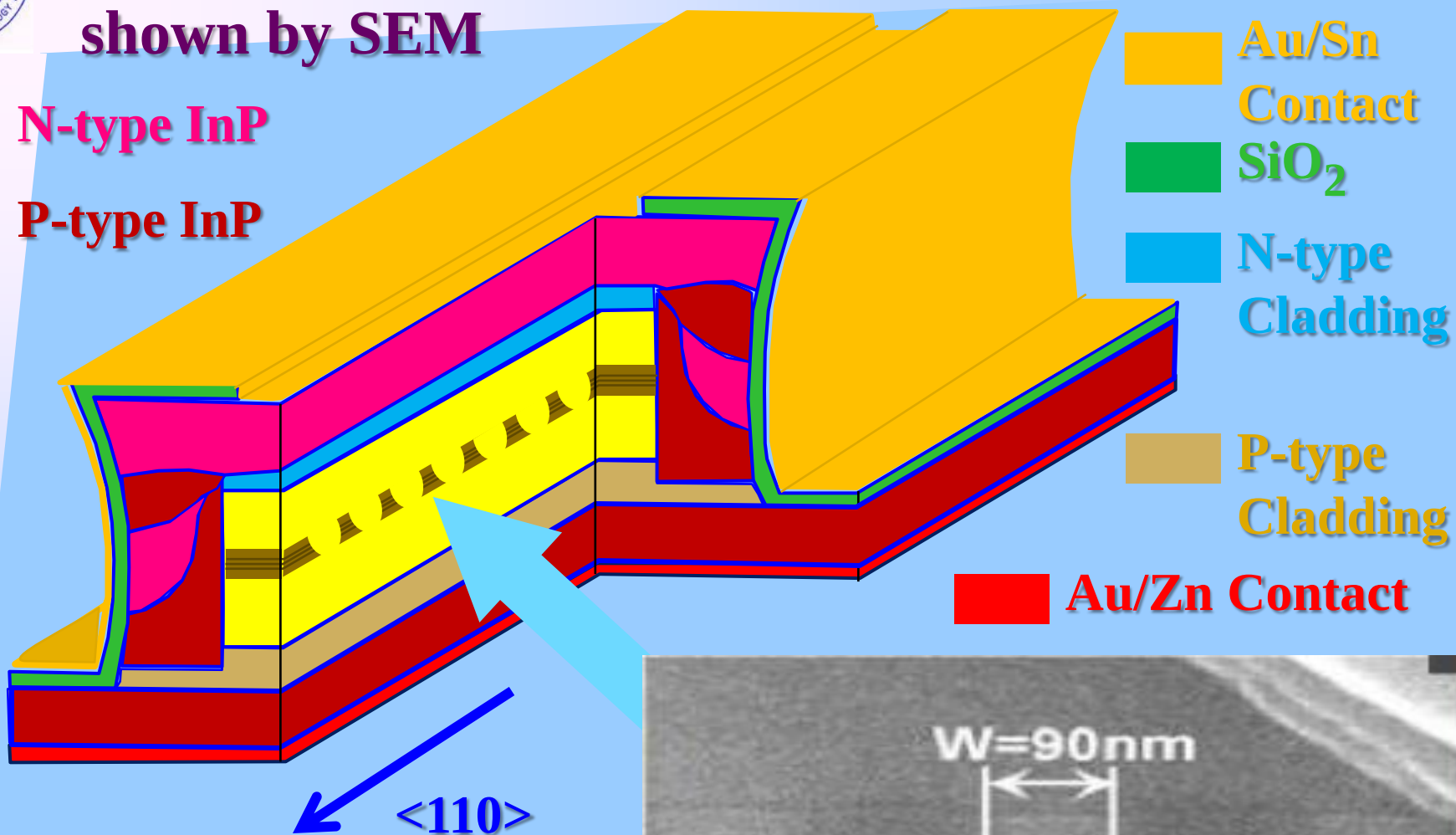
**Bottom Metal Contact**



# DFB Laser fabrication with actual DFB formation shown by SEM

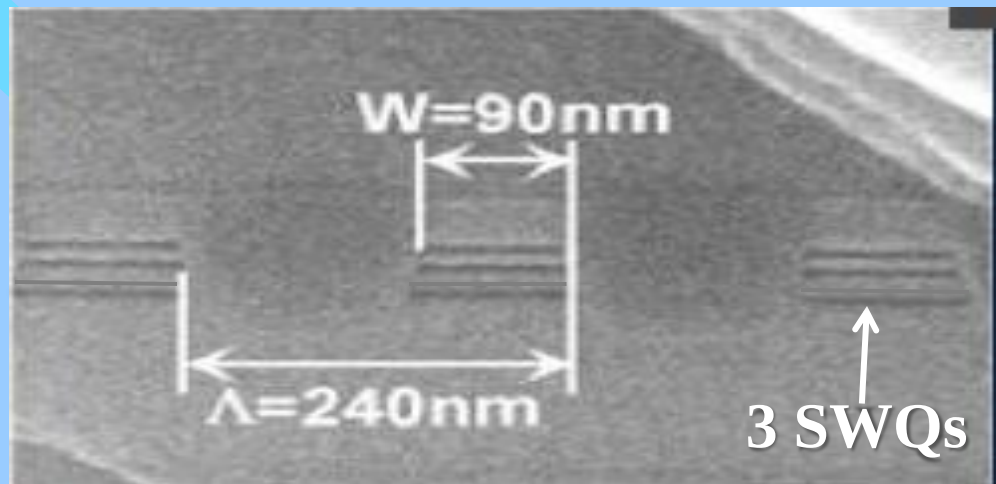
**N-type InP**

**P-type InP**



**P<sup>-</sup>-waveguide**

**Laser Diode with an inbuilt distributed-feedback section.**





# Chirp in DFB Lasers

**When the drive current is modulated:**

- 1. A change in the refractive index (RI) occurs and the resonant  $\lambda_B$  of the grating and that of the laser output changes.**
- 2. During lasing the cavity also heats up which changes the (a) cavity RI and (b) the electron energy gap in the material.**

**In an FP laser “(b)” dominates other effects and is the predominant cause of chirp. In a DFB laser “(b)” is irrelevant as the energy gap covers a range of energies and the DFB  $\lambda_B$  is determined by the grating spacing and the cavity RI. So long as the range of energies in the gap extends to cover the resonant wavelength then the device will lase.**

**This is why DFB laser chirp is far less than that of a FP laser. This effect of the change in RI is much smaller than the effect caused by the change in the energy gap (which dominates in FP lasers but doesn't affect DFBs).**

**MQW-DFB lasers having a low dynamic chirp, therefore, are suitable for high-speed (>5GHz) long haul (>100Km) optical communications.**

**S. J. Wang, L. J. P. Ketelsen, V. R. McCrary, Y. Twu, S. G. Napholtz, and W. V. Werner, IEEE Photon. Technol. Lett., vol. 2(11), 775(1990).**



# Review Questions

1. Why are DFB lasers essentially single mode? How are the modes determined?
2. What is the need for  $\pi/4$  phase slip in a DFB Laser?
3. What is the order of linewidth of a DFB laser? Which factors does it depend on?
4. List the fabrication steps that would be required for the fabrication of a MQW-DFB laser.
5. A DH DBR laser has a cavity  $n_{\text{eff}}=3.4$  of length  $L=100\mu\text{m}$  and is supposed to work at  $\lambda_0=1.55\mu\text{m}$ . The end facets are AR coated with  $R=0.5$  coupled to two gratings of length  $L_{\text{DBR}}=150\mu\text{m}$ . Assuming a coupling coefficient of  $\kappa L_{\text{DBR}}=4$ , for a 1<sup>st</sup> order grating find the grating period ' $\Lambda$ ' and the end-loss of the end facet F-P modes about the selected mode.
6. Why is chirp expected to be much less than that of a Fabry-Perrot Laser