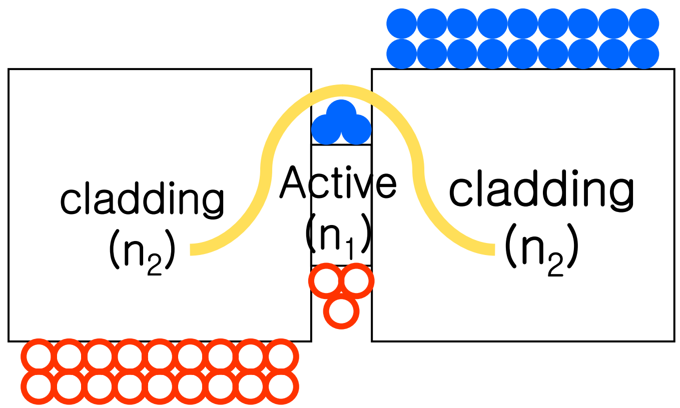
Lect. 21: Single-Mode Semiconductor Laser

Two conditions for lasing: (1) $\Gamma g_{\mathrm{th}} = \alpha_{\mathrm{m}} + \alpha_{\mathrm{int}}$ and (2) $\dfrac{\lambda}{n_{\mathrm{eff}}} = \dfrac{2L}{m}$

There can be several lasing modes: several λ's satisfying above conditions.

(1) Multi-mode waveguide



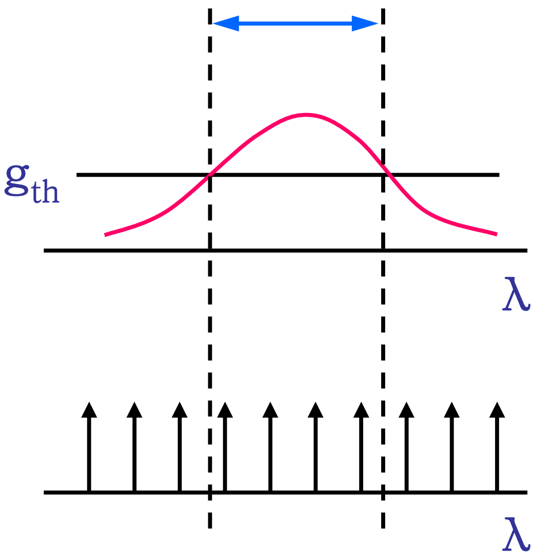
Different modes have different n_{eff}.

=> Design for single guided mode.

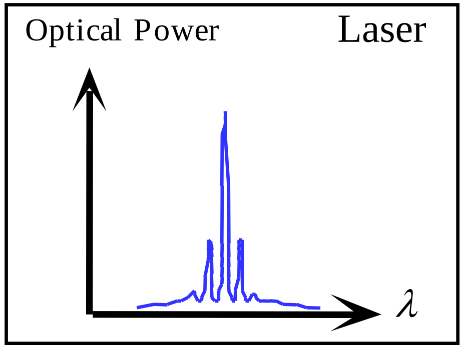
TE, TM modes?

Lect. 21: Single-Mode Semiconductor Laser

Several cavity modes



$$\frac{\lambda}{n_{\text{eff}}} = \frac{2L}{m} \text{ for } g(\lambda) > g_{\text{th}}$$



Mode separation

From $e^{-j2nk_0L} = 1 \Rightarrow 2n_{\text{eff}}k_0L = 2m\pi$

$$\Delta(n_{\text{eff}}k_0)L = \pi \;=>\; \Delta(n_{\text{eff}}k_0) = \frac{\pi}{L}$$

$$\lambda = n_{eff}\frac{2\pi}{k_0} \quad \therefore \Delta\lambda = \frac{\delta\lambda}{\delta k_0}\Delta k = -n_{eff}\frac{2\pi}{k_0{}^2}\Delta k = -\frac{\lambda^2}{2n_{eff}L}$$

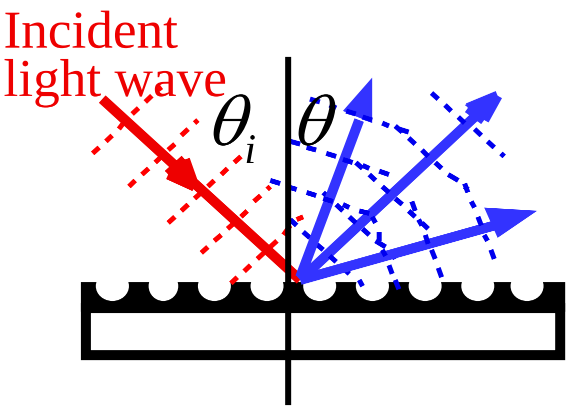
With typical semiconductor lasers with cleaved facets, Δλ is less than gain bandwidth => multi lasing modes

➔ Fabry-Perot laser

Lect. 21: Single-Mode Semiconductor Laser

Single-mode laser for long-distance, high-speed optical communications?

Use another type of mirror: Grating



$$d\left(\sin\theta - \sin\theta_i\right) = m \cdot \lambda$$

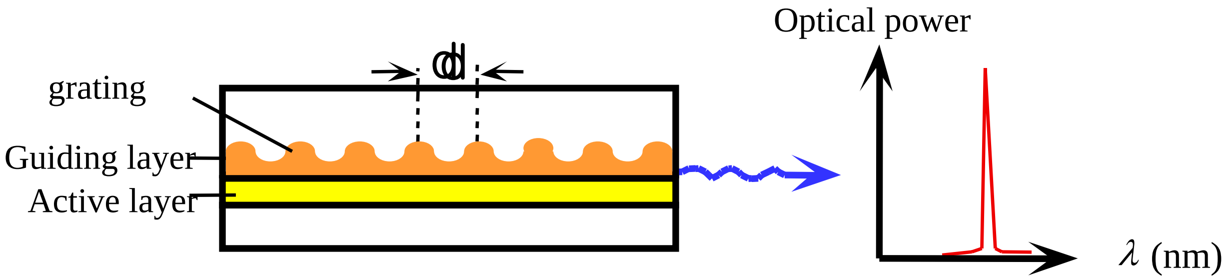
For $\theta_i = 90^\circ$ and $\theta = -90^\circ$,

$$d = m\frac{\lambda}{2}$$

Lect. 21: Single-Mode Semiconductor Laser

How to implement diffraction grating within semiconductor laser?

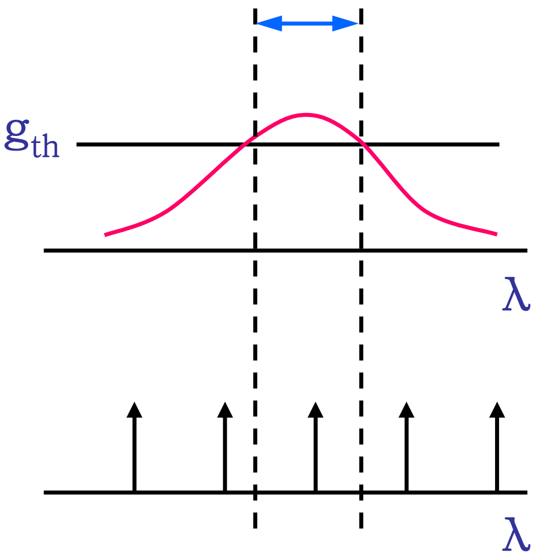
Distributed Feedback (DFB) Laser



$$d = m\frac{\lambda}{2n_{eff}} \quad \text{(typically m=1)}$$

Lect. 21: Single-Mode Semiconductor Laser

Another approach: Make L very small so that $\Delta\lambda$ larger than gain bandwidth



$$|\Delta\lambda| = \frac{\lambda^2}{2n_{eff}L}$$

gain bandwidth: in the order of 10nm

λ : 1.5μm

n_{eff} : 3.5

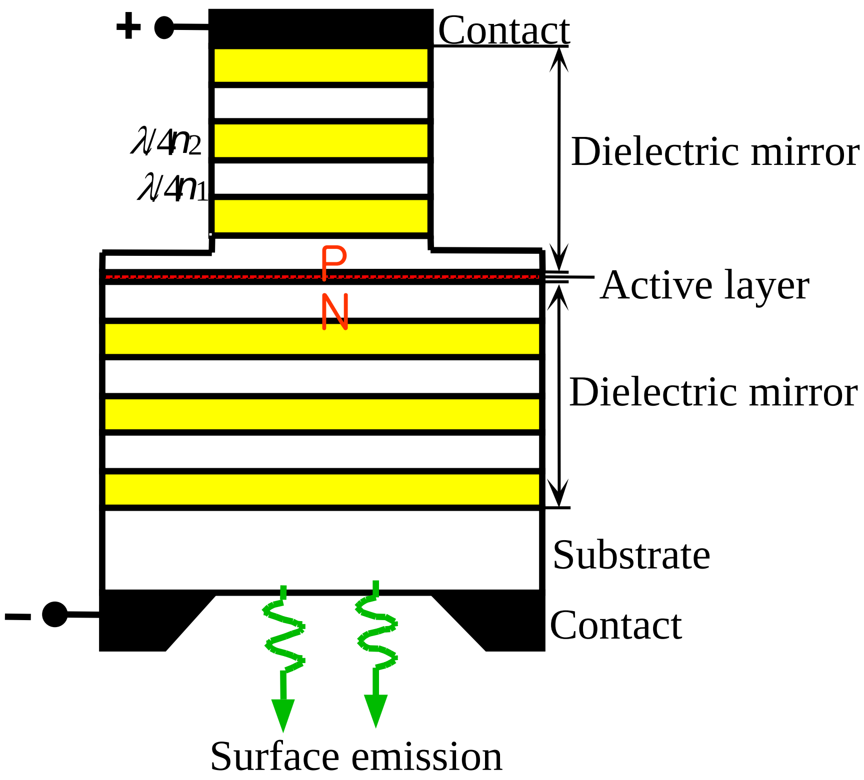
$L \sim 30\mu$m;

Not easy to fabricate by cleaving

From $\alpha_m = \frac{1}{L}\ln\frac{1}{R}$, too much mirror loss

Lect. 21: Single-Mode Semiconductor Laser

Solution: Very short cavity vertical lasers with very high reflectivity mirrors (VCSEL: Vertical Cavity Surface Emitting Laser)



In semiconductor fabrication, vertical thickness can be very precisely controlled.

Dielectric mirror can have high reflectivity approaching R=1.

From $\alpha_m = \frac{1}{L}\ln\frac{1}{R}$,

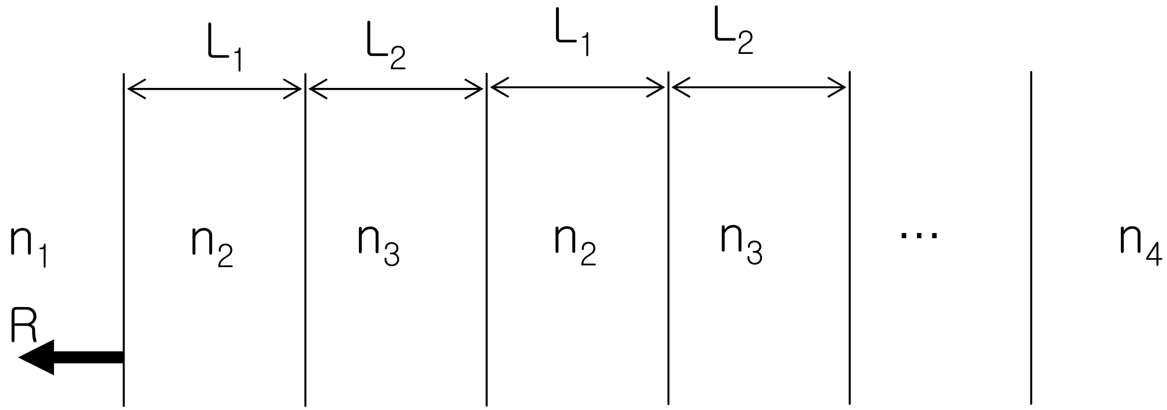
α_m can be made small if R approaches 1.

VCSELs are cheap because it is easy to make.

Lect. 21: Single-Mode Semiconductor Laser

Review: High-Reflection Coating => Dielectric mirror

Repeat the quarter-wavelength pair m times.



$$R = \left(\frac{n_1 - \left(\frac{n_2}{n_3}\right)^{2m} n_4}{n_1 + \left(\frac{n_2}{n_3}\right)^{2m} n_4} \right)^2$$

$$\text{If } n_2 > n_3,\ R \sim \left(\frac{-(n_2/n_3)^{2m} n_4}{+(n_2/n_3)^{2m} n_4} \right)^2 = 1$$

$$\text{If } n_2 < n_3, R \sim \left(\frac{n_1}{n_1} \right)^2 = 1$$

Lect. 21: Single-Mode Semiconductor Laser

Exercise Problems:

Prob. 9, Prob. 12, Prob. 15, Prob. 18, Prob. 20, Prob. 23 in Part 3

Schedule for coming weeks:

- Nov. 21: Quiz 8, Lect. 22
- Nov. 23: Lect. 23

- Nov. 28: Quiz 9, Research Presentation (고민수, 윤순준)
- Nov. 30: Research Presentation (이명재, 홍문기)
- Dec. 5: Research Presentation (오택일)

➔25 minutes for each presentation

Lect. 21: Single-Mode Semiconductor Laser

Special Topic Presentation

40 min. presentation on one of following topics:
- Nonlinear Optics in Fiber (이명재)
- Silicon Raman Laser (홍문기)
- Photonic Crystal (윤순준)
- Slow Light (고민수)
- Quantum Cascade Lasers (오택일)

- Dec. 5: 고민수
- Dec. 7: 윤순준
- Dec. 12: 이명재, 홍문기
- Dec. 14: 오택일

➔ Dinner together on Dec. 14