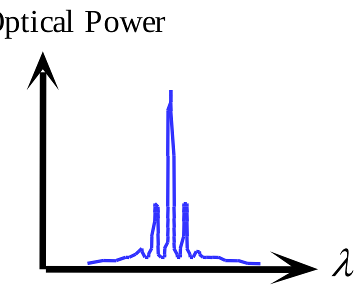
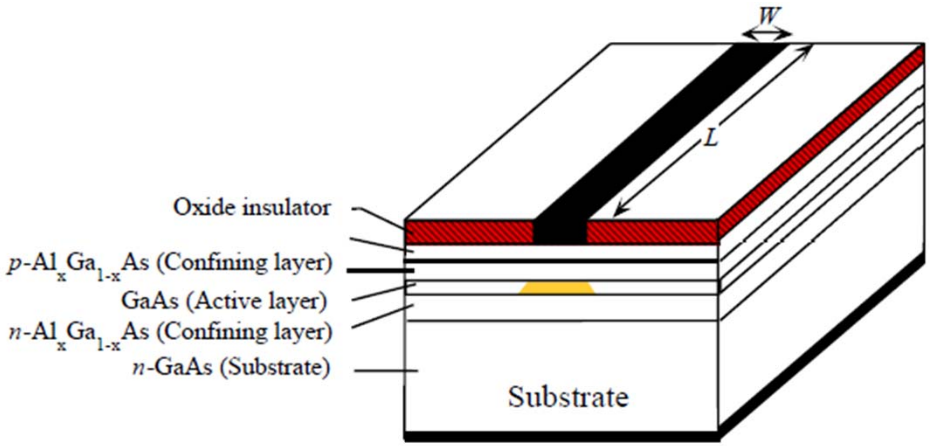
Lect. 25: Single-Mode Semiconductor Lasers

Semiconductor laser usually have multiple lasing modes





2-Dimensional dielectric waveguide

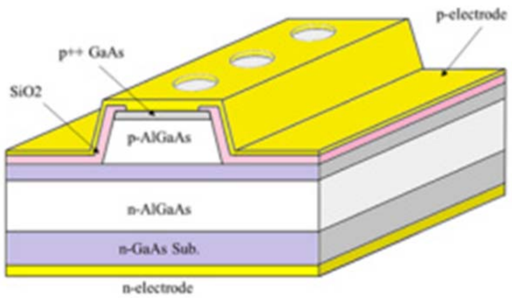
For vertical waveguide

➔Minimize active region thickness

For lateral waveguide

➔ Ridge/rib waveguide

➔ Inject currents into a small region

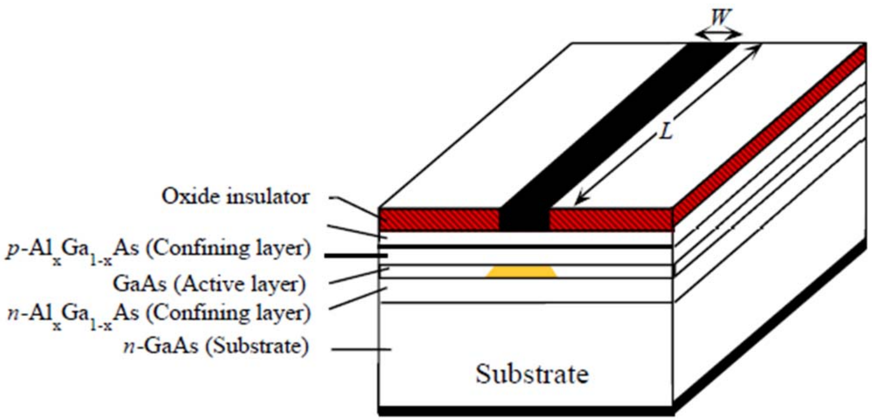


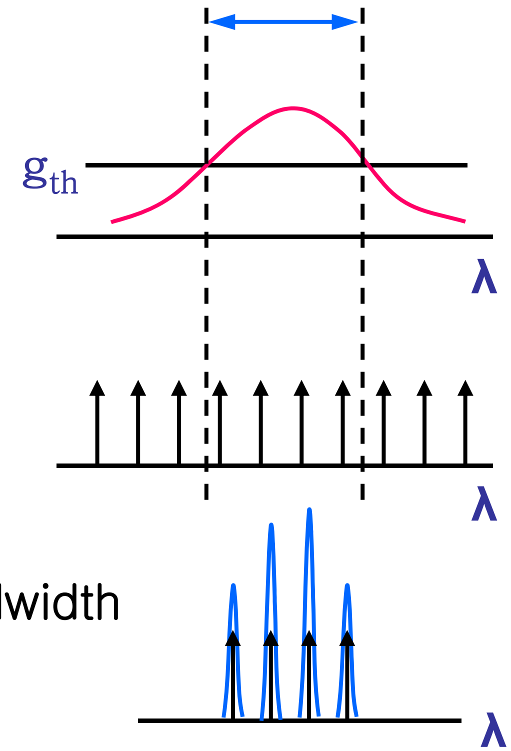
Single waveguide mode

But multiple lasing mode?

Lect. 25: Single-Mode Semiconductor Lasers

Lasing conditions: (1) $\Gamma g_{\text{th}} = \alpha_{\text{m}}$ and (2) $\dfrac{\lambda}{n_{\text{eff}}} = \dfrac{2L}{m}$





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

➔ Fabry-Perot laser

Mode separation $\Delta\lambda = \dfrac{\lambda^2}{2n_{eff}L}$

Lect. 25: Single-Mode Semiconductor Lasers

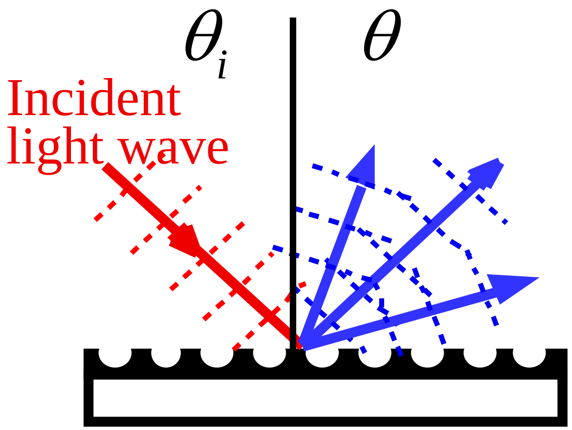
Problem with multi-mode laser?

Modal dispersion even with single-mode fiber
(refractive index is function of wavelength)

How to make single-mode laser?

Use λ-selective mirror: Grating

Remember



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

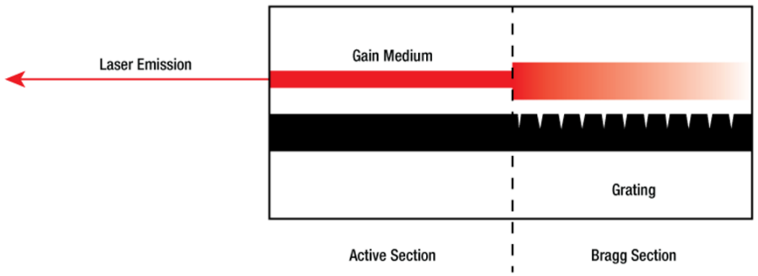
For mirror, $\theta_i = 90^\circ$ and $\theta = -90^\circ$,

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

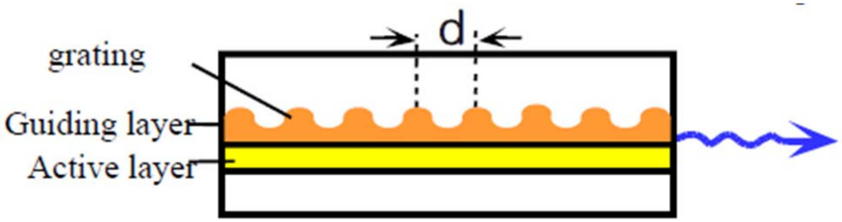
Lect. 25: Single-Mode Semiconductor Lasers

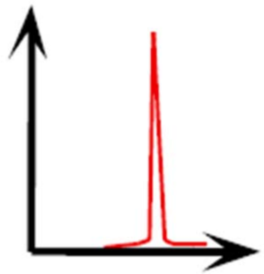
How to implement diffraction grating within semiconductor laser?

Distributed Bragg Reflector (DBR) Laser



Distributed Feedback (DFB) Laser

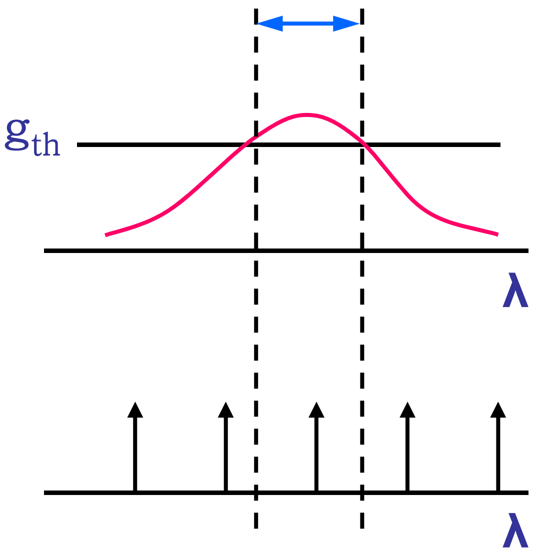




$$d = m\frac{\lambda}{2n_{\text{eff}}} \quad \text{(typically m=1)}$$

Lect. 25: Single-Mode Semiconductor Lasers

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

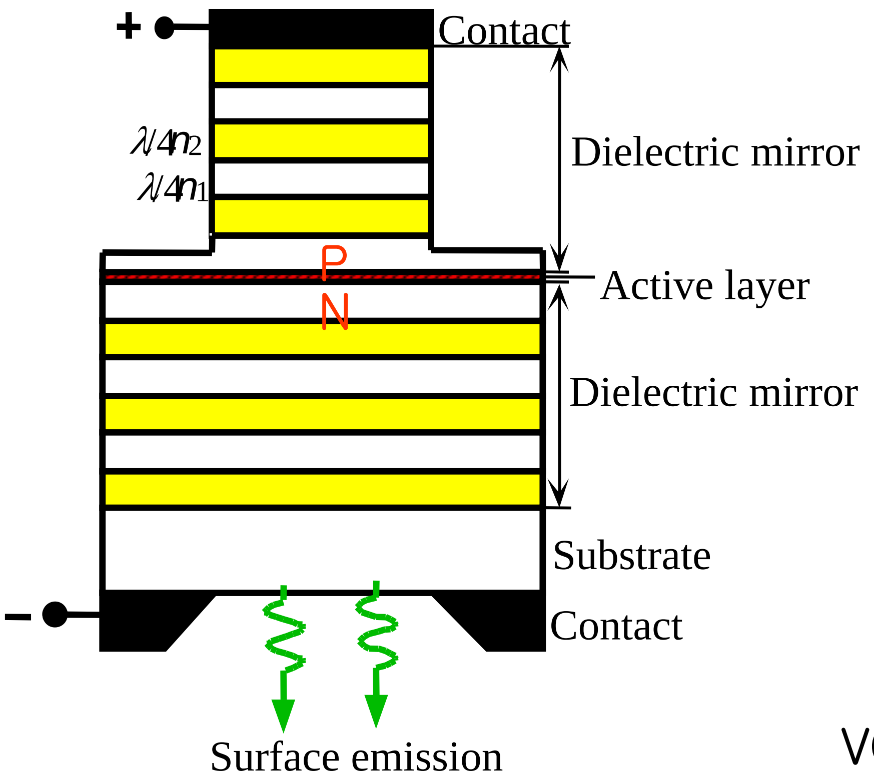
$L \sim 30\mu$m;

Not easy to fabricate by cleaving

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

Lect. 25: Single-Mode Semiconductor Lasers

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

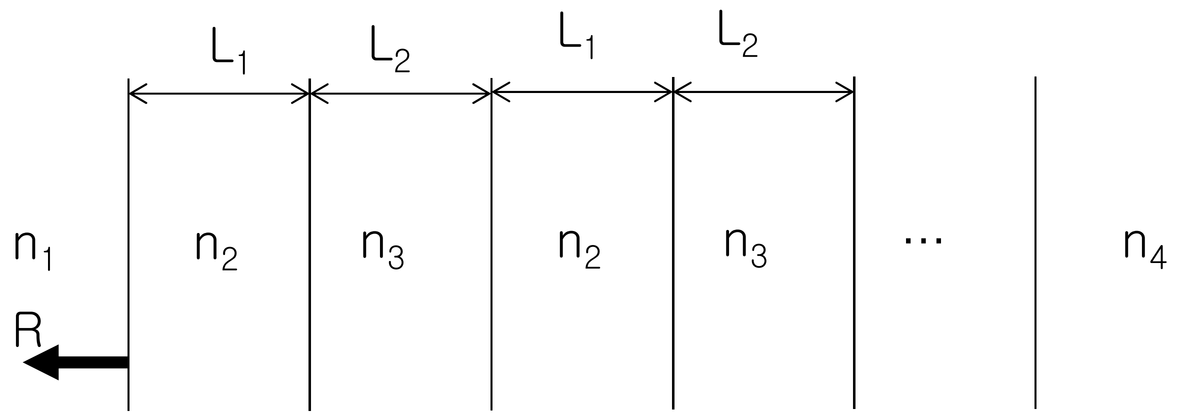
α_m can be made small if R approaches 1.

VCSELs are cheaper because it is more mass-producible

Lect. 25: Single-Mode Semiconductor Lasers

Review: High-Reflection Coating => Dielectric mirror

Repeat the quarter-wavelength pair m times.



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

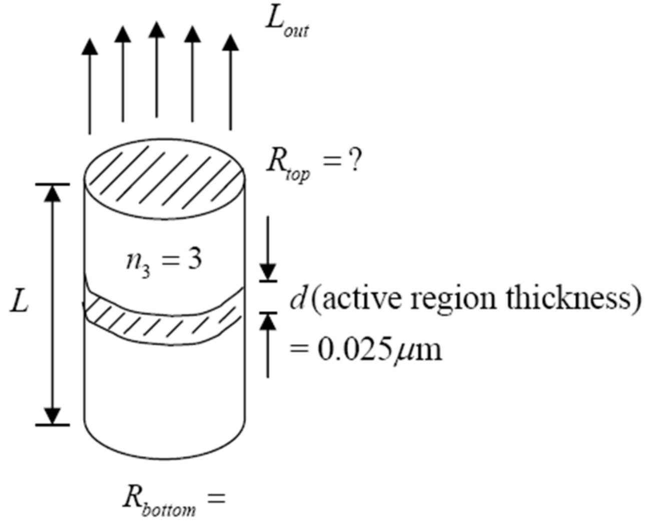
If $n_2 > n_3,\ R \sim \left(\frac{-\left(n_2/n_3\right)^{2m} n_4}{+\left(n_2/n_3\right)^{2m} n_4} \right)^2 = 1$

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

Lect. 25: Single-Mode Semiconductor Lasers

Homework

Prob. 1 We want to design a circular VCSEL (Vertical Cavity Surface Emitting Laser) lasing at 1um whose structure is shown below. The values for important laser and material parameters are also given. For simplicity, assume there is no internal loss, the optical confinement factor is 1, the refractive indices for both active region and claddings are 3 (n_1 = 3), and the bottom mirror has the reflectivity of 1.



gain at 1μm

$g = a(n - n_0)$

$a : 2.5\times10^{-16} / cm^2$

$n_0 : 10^{18} / cm^3$

τ (carrier lifetime) = 1nsec

radius: 5μm

Lect. 25: Single-Mode Semiconductor Lasers

Homework (continued)

(a) Determine the minimum possible value for L, the laser cavity length.

(b) We want the VCSEL to have the threshold current of 1mA. What is n_{th}, the threshold carrier density in cm^{-3}, and g_{th}, threshold gain in cm^{-1}?

(c) What is the top mirror reflectivity in order to realize (b)?

(d) The top mirror can be realized by stacking up two materials: one with n_2 = 2.2 and the other with n_3 = 1.1. What is the layer thickness for n_2 and n_3?

(e) Which layer should be stacked first, layer with n_2 or n_3? Why? Assume the active region is in the middle of the laser cavity.

(f) What is the minimum number of staked layers required? Assume the laser is located in the vacuum.