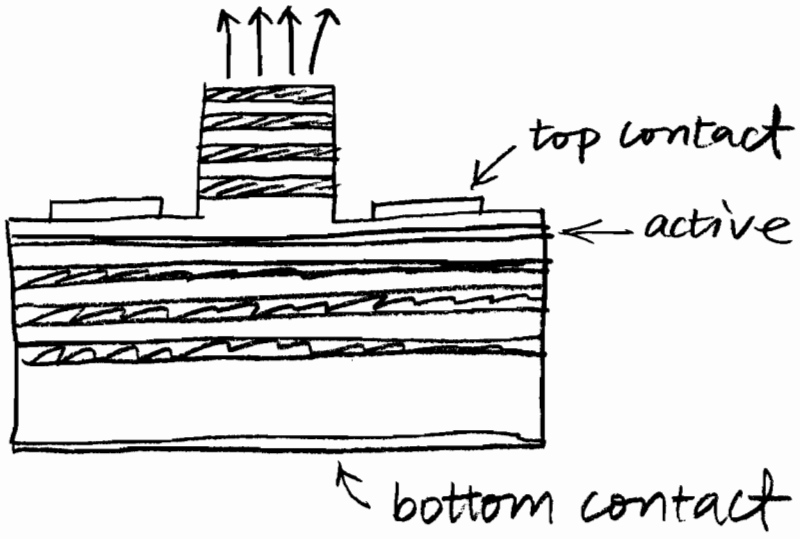
Vertical Cavity Surface-Emitting Laser (VCSEL)



Essentially a vertical DBR laser with epitaxially grown DBRs.

Key feature

- Short cavity length. (~ μm)
  - * min. spacing between top and bottom DBRs $= \frac{\lambda_g}{2}$
- Extremely short gain region (~10 nm for SQW)
- Need extremely high reflectivity DBRs

$$\Gamma g = \alpha + \frac{1}{2L} \ln \frac{1}{R_1 R_2}$$

To achieve same α_m

$L = 250\ \mu m$ $R_1 = R_2 = 30\%$ $\alpha_m = 48\ m^{-1}$

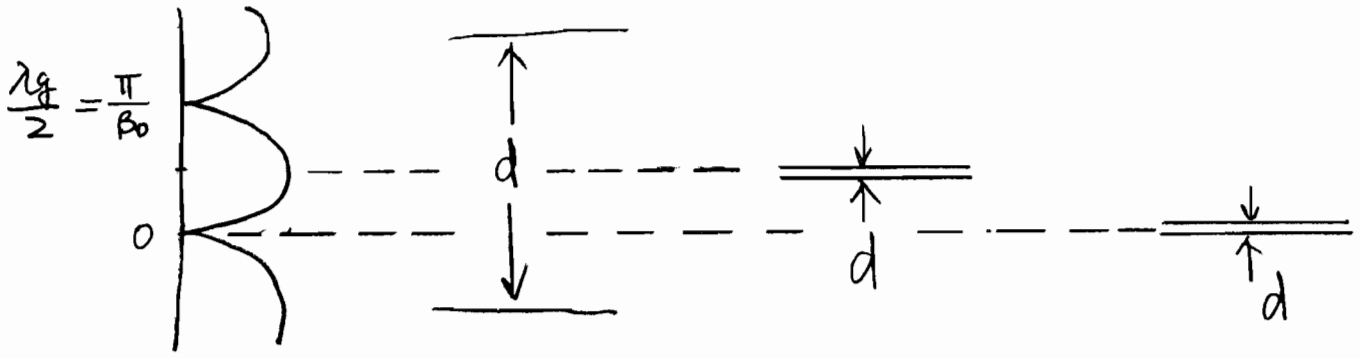
$L = 1\ \mu m$ $R_1 = R_2 = 99.5\%$ $\alpha_m = 50\ m^{-1}$

$$\Gamma = \left(\gamma \frac{d}{L}\right) \cdot \xi$$

↳ lateral (overlap of mode and structure)

$\frac{d}{L}$: "duty cycle" of active layer

γ : related to position of active layer



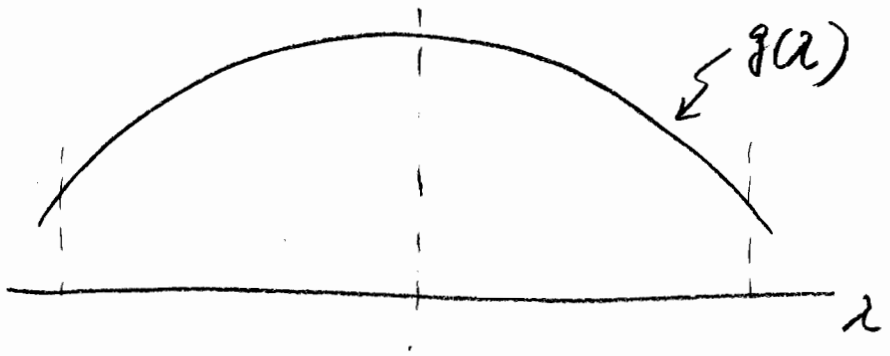
standing-wave pattern inside cavity	thick active layer	thin active layer @ peak	thin active layer @ null
	$\gamma = 1$	$\gamma = 2$	$\gamma = 0$

$$\int_0^{\frac{\lambda_g}{2}} \sin^2(\beta_0 x)\, dx = \int_0^{\frac{\lambda_g}{2}} \left(\frac{1}{2} + \frac{1}{2}\cos(2\beta_0 x)\right) dx = \frac{1}{2} \cdot \frac{\lambda_g}{2} = \frac{1}{2} d$$

$$\int_{\frac{\lambda_g}{4} - \frac{d}{2}}^{\frac{\lambda_g}{4} + \frac{d}{2}} \sin^2(\beta_0 x)\, dx \approx \int_{\frac{\lambda_g}{4} - \frac{d}{2}}^{\frac{\lambda_g}{4} + \frac{d}{2}} 1 \cdot dx = 1 \cdot d$$

Practical benefits of VCSEL

- Single longitudinal mode



mode spacing ~ 100x compared w/ edge-emitter

- 2-D array

- Low threshold.

$$I_{th} \sim \frac{N_{th} q}{\eta_i \tau} \cdot (w \cdot w \cdot d)$$

$w \sim 1\,\mu m$

$d \sim 10\,nm$

much smaller active volume.

- wafer scale processing (no cleaving necessary)

- symmetric emission pattern.
  (circular far-field pattern with low N.A.)