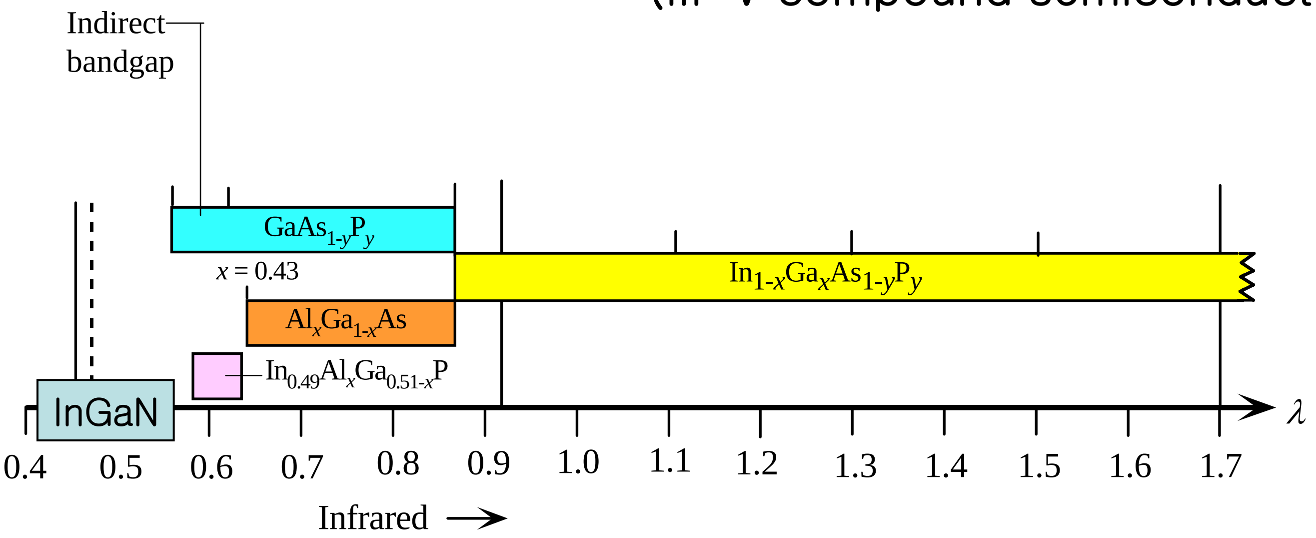
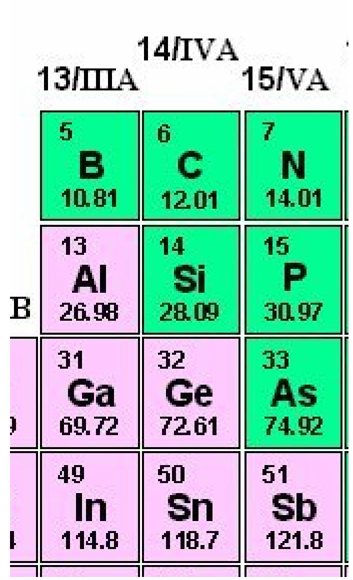
# Lect. 20: Semiconductor Laser

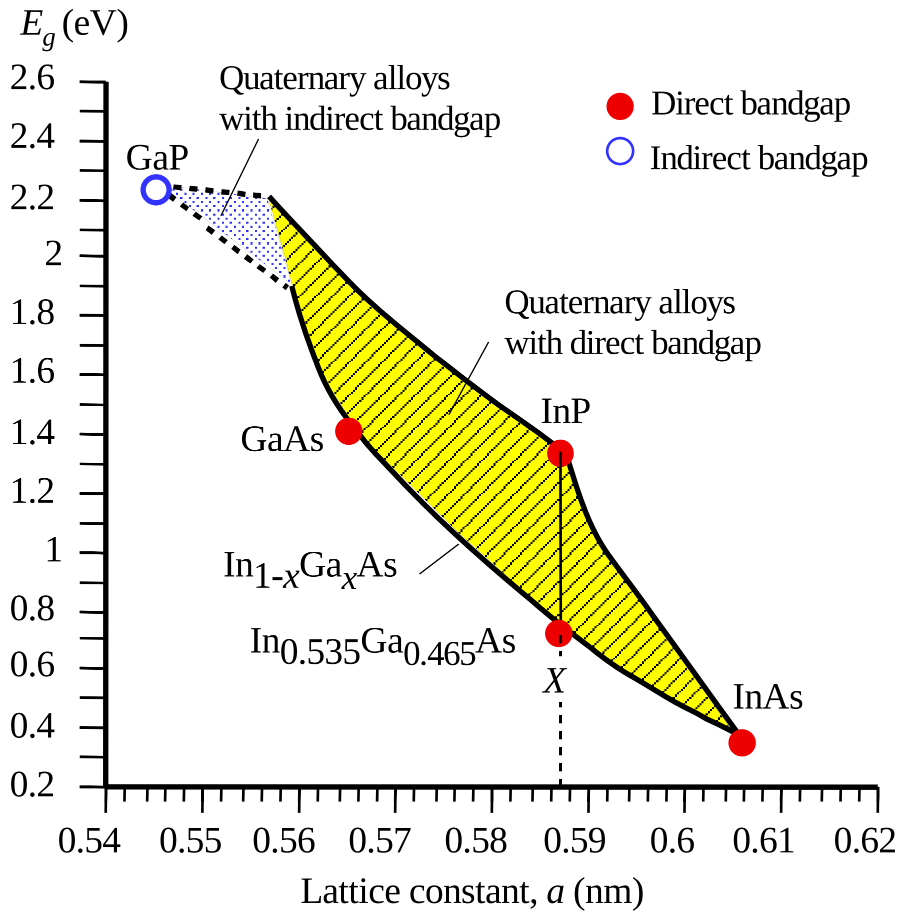
- Semiconductors lasers are small, cheap and very efficient.

- Wavelength: Bandgap of direct semiconductor materials
  (III-V compound semiconductors)



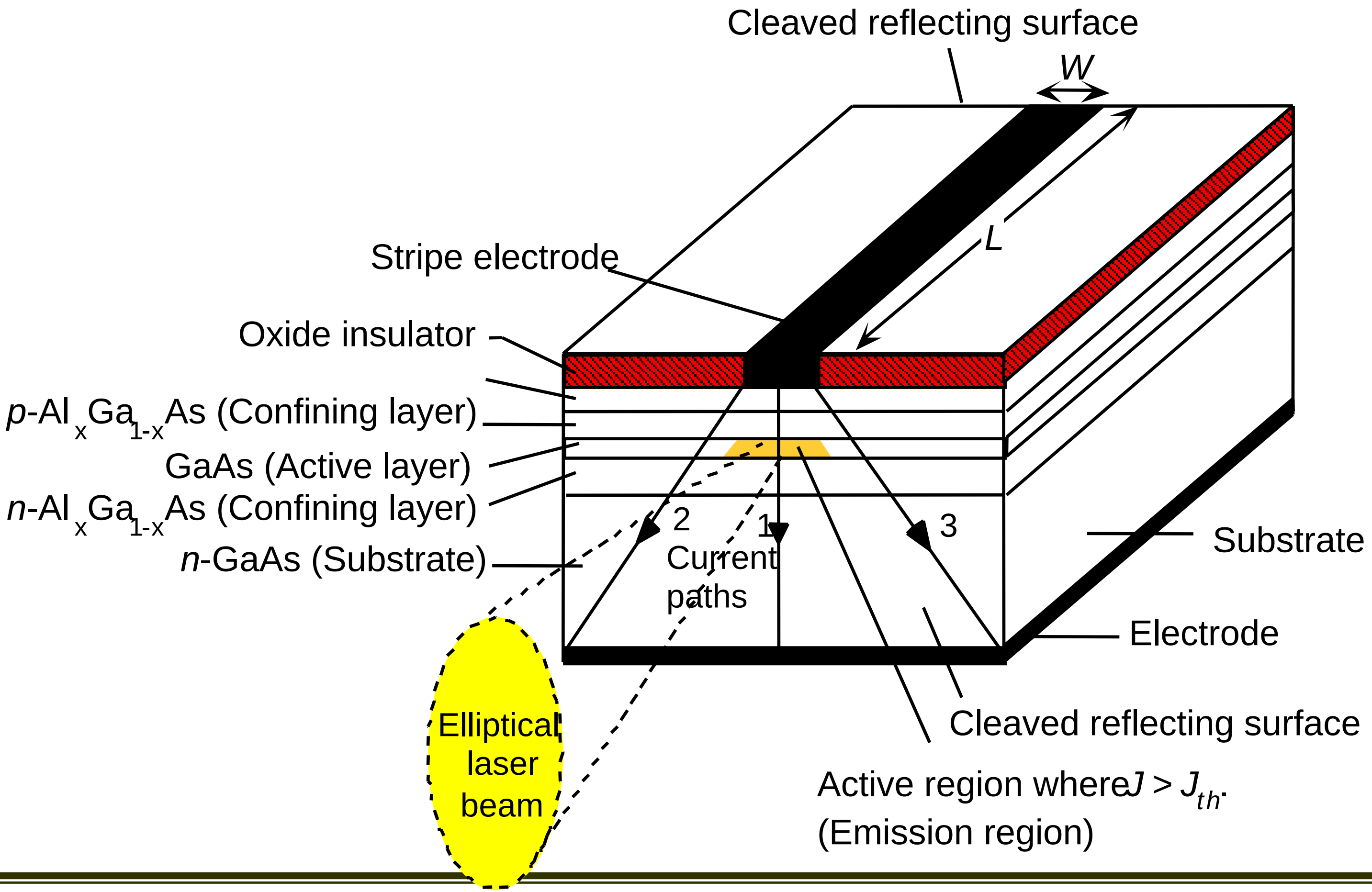



# Lect. 20: Semiconductor Laser



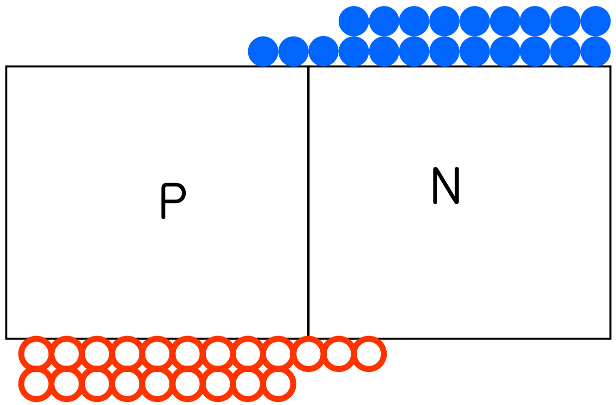
# Lect. 20: Semiconductor Laser

Semiconductor Laser Structure: PN Junction + Mirror (Cleaved Facets)

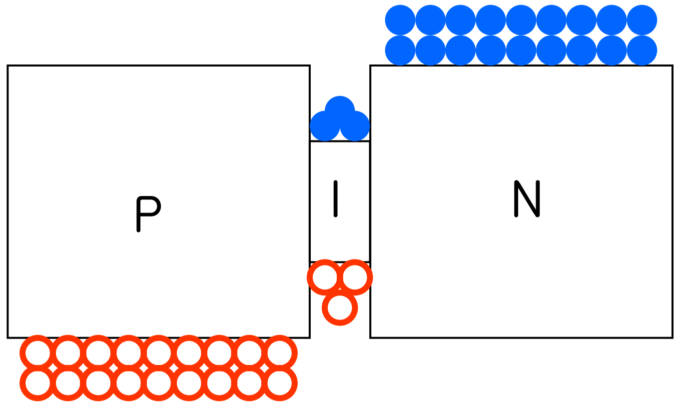


# Lect. 20: Semiconductor Laser

Efficient carrier confinement: PIN structure with large $E_g$ for P, N regions




Injected carriers are spread-out
=> smaller density

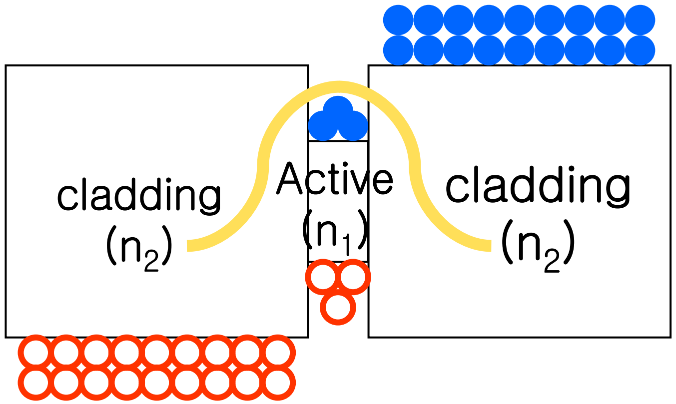



Double heterojunction: Confinement of Injected carriers
=> larger density

For population inversion, $\dfrac{N_2 \cdot P_1}{N_1 \cdot P_2} > 1$

# Lect. 20: Semiconductor Laser

Efficient photon confinement: PIN structure with smaller n  for P, N regions




Smaller $E_g$ material has larger n
($n_1$>$n_2$)

=> more photons in the active region
and larger $\Gamma$

With $\Gamma$<1

$$g_{th} = \frac{1}{L} \ln \frac{1}{R} \Rightarrow \Gamma g_{th} = \frac{1}{L} \ln \frac{1}{R} = \alpha_m \text{(mirror loss)}$$

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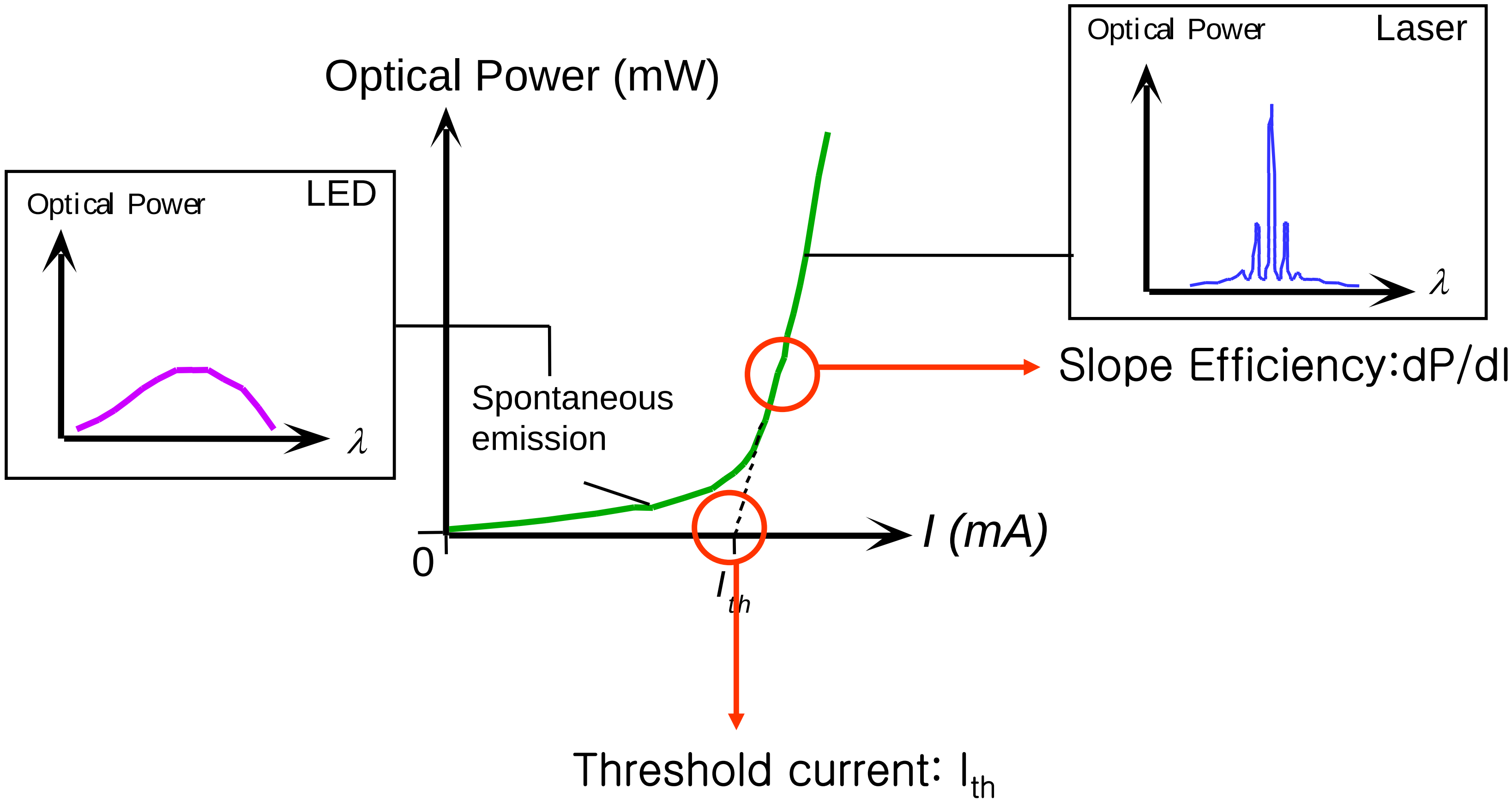
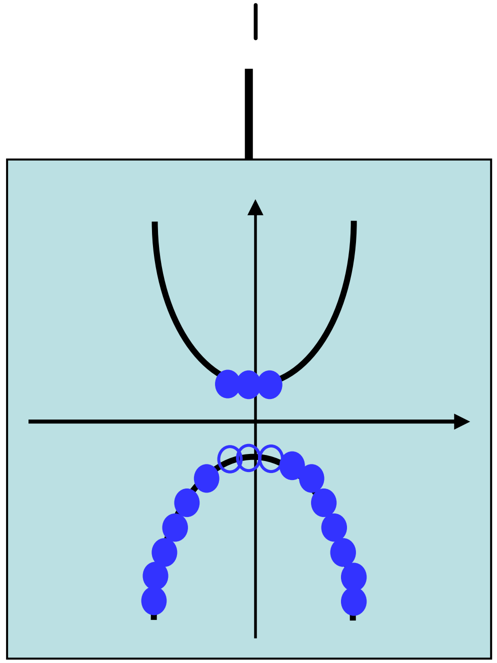


# Lect. 20: Semiconductor Laser

Analytical expression for $I_{th}$

Assume optical gain increases linearly with injected carriers: $g = a(N - N_0)$




- Carrier density required for lasing ($N_{th}$):

$$\text{Since } g_{\text{th}} = \frac{\alpha_{\text{m}}}{\Gamma}, \quad N_{th} = \frac{g_{th}}{a} + N_0 = \frac{\alpha_{\text{m}}}{\Gamma a} + N_0$$

- Relationship between $N$ and $I$

$$\frac{dN}{dt} = \frac{I}{qV} - \frac{N}{\tau};$$

($V$ : volume of active region, $\tau$ : carrier life time)

$$\text{In steady-state, } I = \frac{N}{\tau} \cdot qV$$

- Current required for lasing ($I_{th}$) : $I_{th} = \frac{N_{th}}{\tau} \cdot qV = (\frac{\alpha_{\text{m}}}{\Gamma a} + N_0)\frac{1}{\tau} \cdot qV$

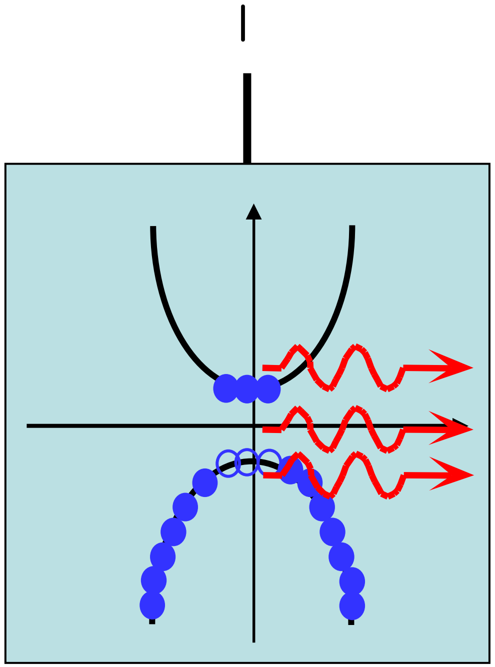
# Lect. 20: Semiconductor Laser

Analytical expression for dP/dI

Assume injected carriers are all converted into photons by stimulated emission when I>Ith

– Change in photon density with time

$$\frac{dn_{ph}}{dt} = \frac{I - I_{th}}{qV} - \frac{n_{ph}}{\tau_{ph}}; \quad \tau_{ph} = \frac{1}{v \cdot \alpha_{\mathrm{m}}}$$




– At steady-state,

$$n_{ph} = \frac{I - I_{th}}{qV} \cdot \tau_{ph}$$

– Output power

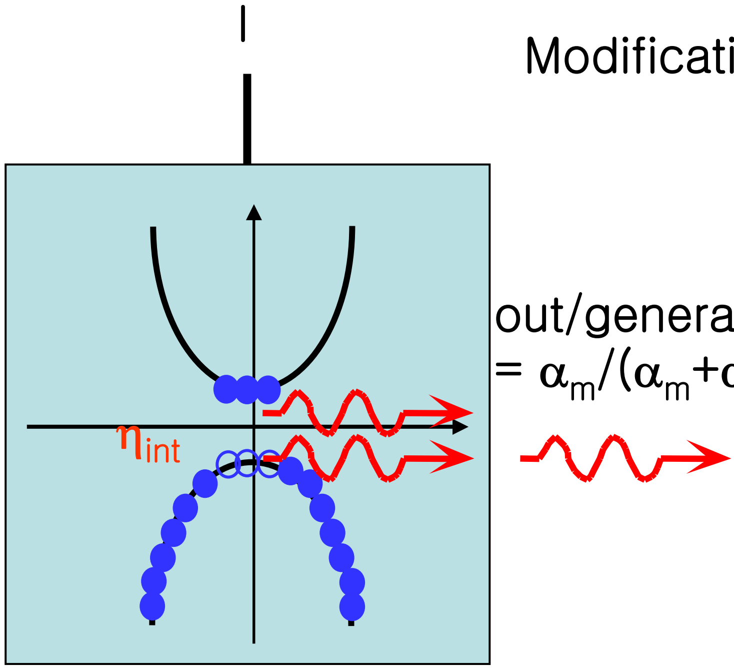
$$P_{out} = \frac{\hbar\omega n_{ph} V}{\tau_{ph}} = \hbar\omega \frac{I - I_{th}}{qV} \cdot \tau_{ph} \frac{V}{\tau_{ph}} = \hbar\omega \frac{I - I_{th}}{q}$$

# Lect. 20: Semiconductor Laser

Refinements:

–Injected carriers are not entirely converted into photons: conversion efficiency, $\eta_{int}$.

– Photons can be lost internally by impurities, scattering, ··· : internal loss, $\alpha_{int}$




out/generation = $\alpha_m/(\alpha_m+\alpha_{int})$

Modifications:

$$g_{th} = \frac{\alpha_m + \alpha_{int}}{\Gamma}$$

$$I_{th} = \left(\frac{\alpha_m + \alpha_{int}}{\Gamma a} + N_0\right)\frac{1}{\tau}\cdot qV$$

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Refinements:

–Injected carriers are not entirely converted into photons: conversion efficiency, $\eta_{int}$.

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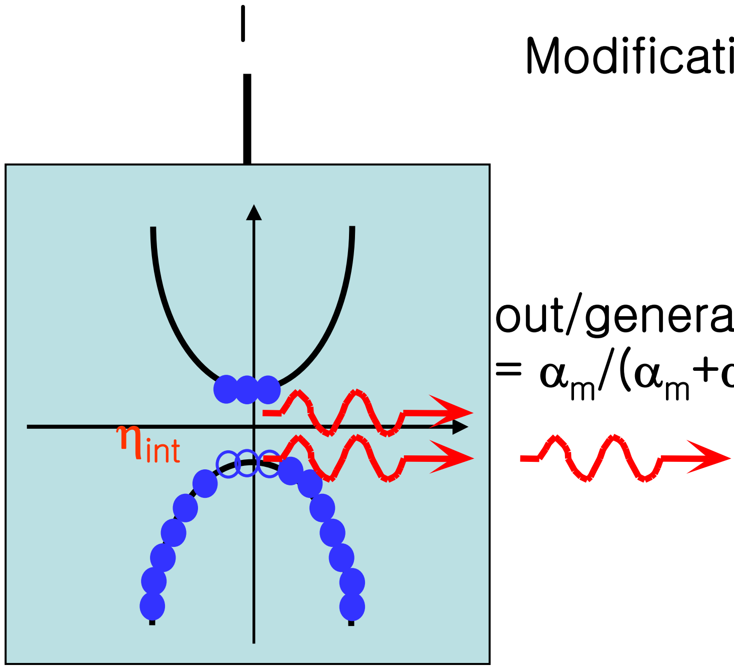



Modifications:

out/generation = $\alpha_m/(\alpha_m+\alpha_{int})$

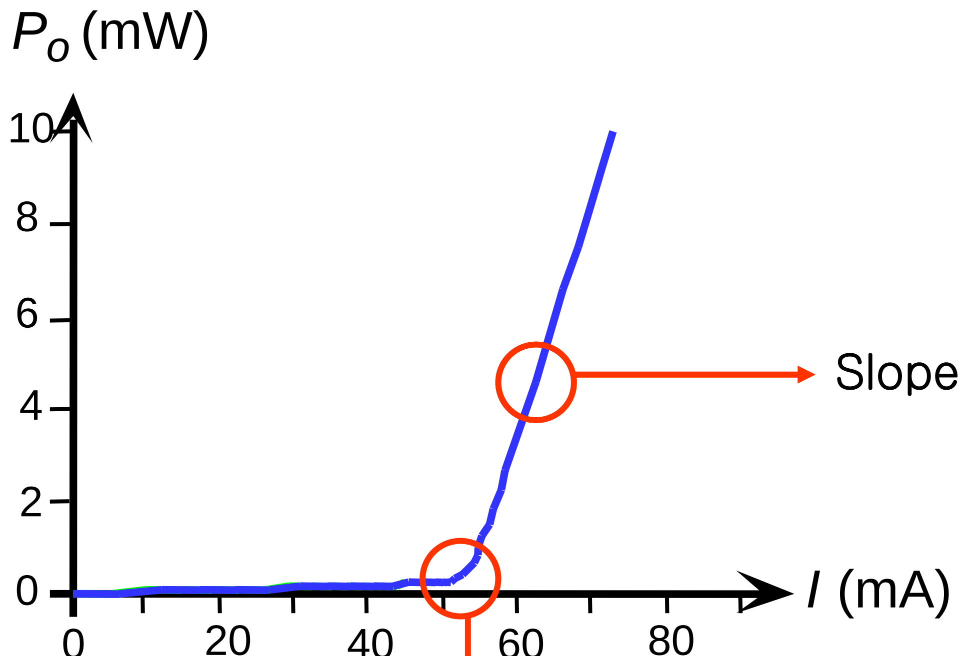
$$\tau_{ph} = \frac{1}{v\cdot(\alpha_m + \alpha_{int})} \quad \text{and} \quad \tau_{ph,m} = \frac{1}{v\cdot\alpha_m}$$

$$n_{ph} = \eta_{int}\frac{I - I_{th}}{qV}\cdot\tau_{ph}$$

$$P_{out} = \frac{\hbar\omega n_{ph} V}{\tau_{ph,m}} = \hbar\omega\cdot(\eta_{int}\frac{I-I_{th}}{qV}\tau_{ph})\frac{V}{\tau_{ph,m}}$$

$$= \frac{\hbar\omega}{q}\cdot\frac{\tau_{ph}}{\tau_{ph,m}}\cdot\eta_{int}(I - I_{th})$$

$$= \frac{\hbar\omega}{q}\frac{\alpha_m}{\alpha_m + \alpha_{int}}\eta_{int}(I - I_{th})$$




Slope Efficiency:

$$\frac{dP}{dI} = \frac{\hbar\omega}{q}\frac{\alpha_m}{\alpha_m + \alpha_{int}}\eta_{int}$$

$$\eta_{ext} = \frac{\alpha_m}{\alpha_m + \alpha_{int}}\eta_{int}$$

Threshold current: $I_{th} = (\frac{\alpha_m + \alpha_{int}}{\Gamma a} + N_0)\frac{1}{\tau} \cdot qV$