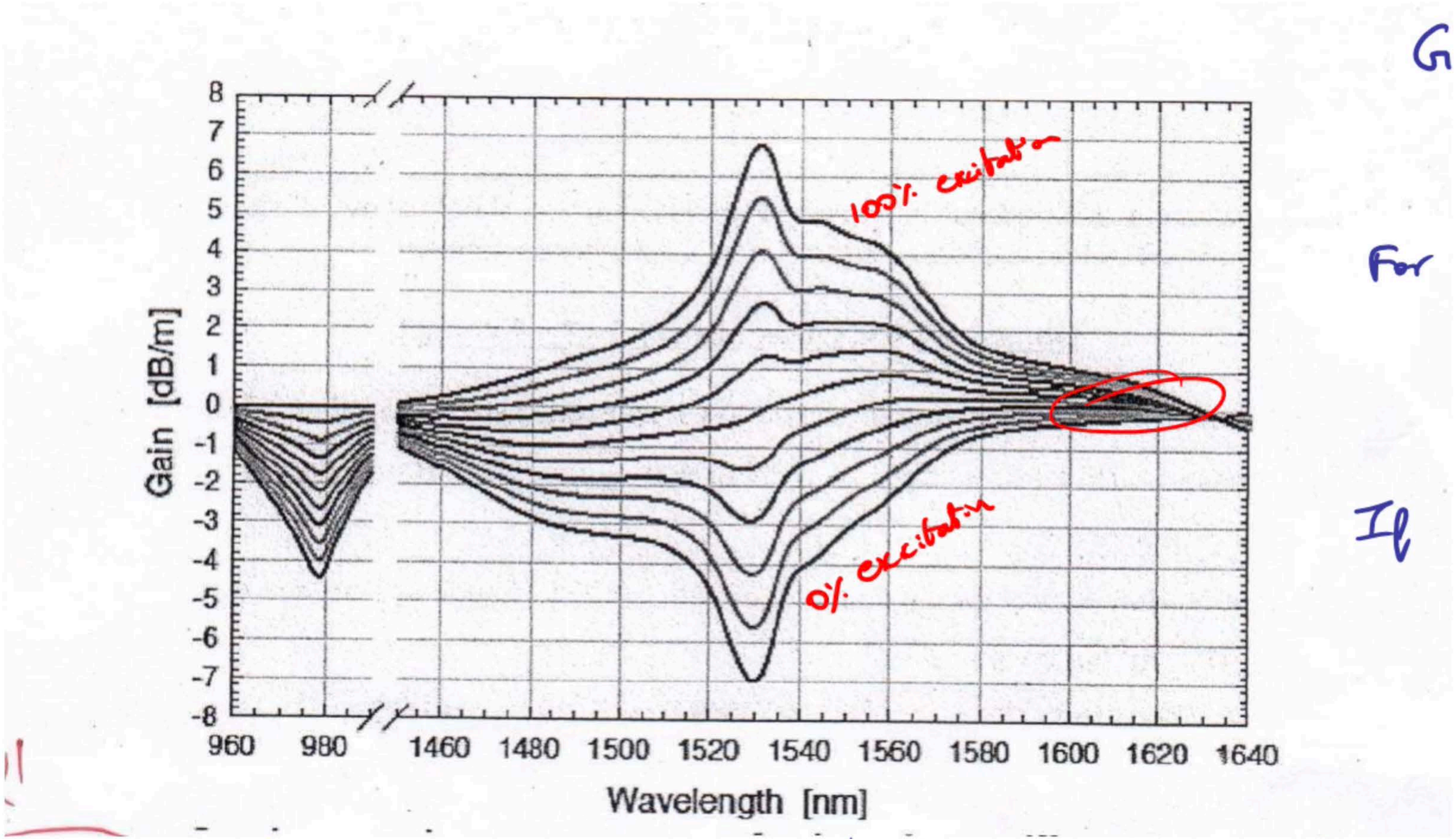


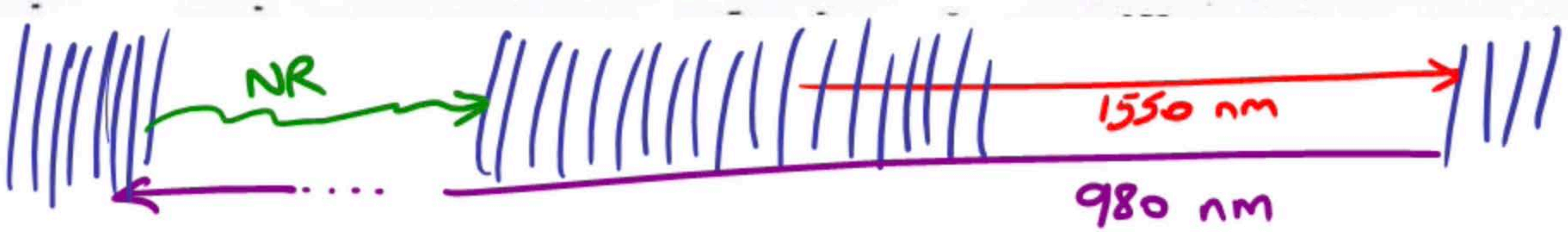
$$G = \frac{P_s(L)}{P_s(0)} = \exp\left[\int_0^L \underbrace{\left(N_2\sigma_e^s - N_1\sigma_a^s\right)}_{\text{gain coefficient } \gamma(z)} dz\right]$$

For uniform excitation

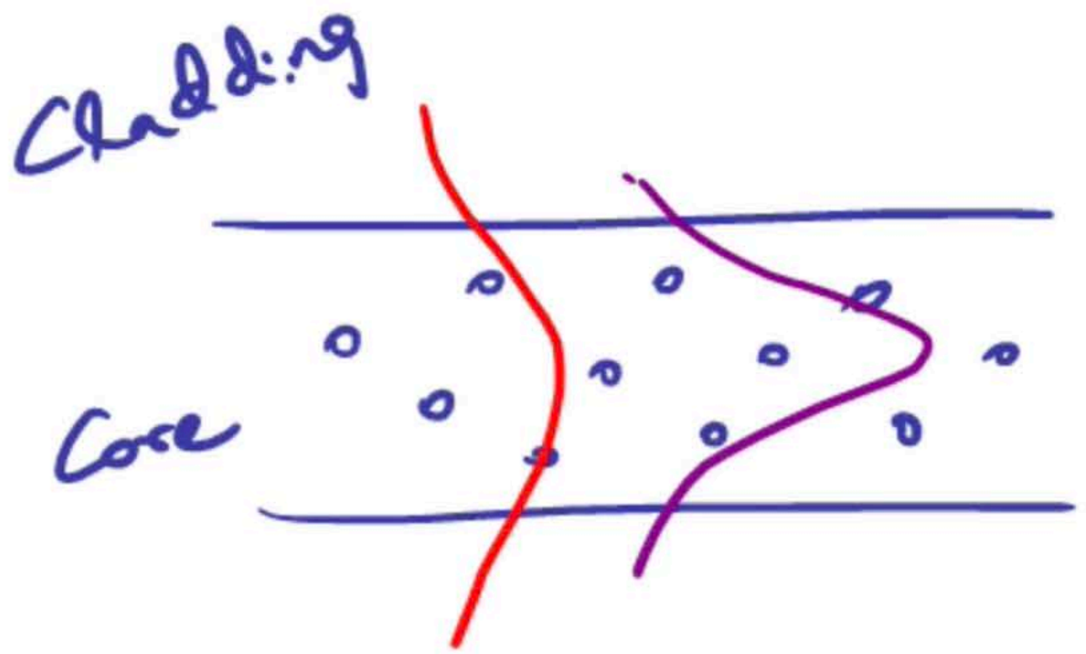
$$G = \exp\left[\left(N_2\sigma_e^s - N_1\sigma_a^s\right)L\right]$$

If $\sigma_e^s > \sigma_a^s$, N_2 need NOT be greater than N_1

$\sigma_e^s < \sigma_a^s$, Sufficiently high N_2 over N_1 can provide gain



Pump-signal overlap factor (Γ)



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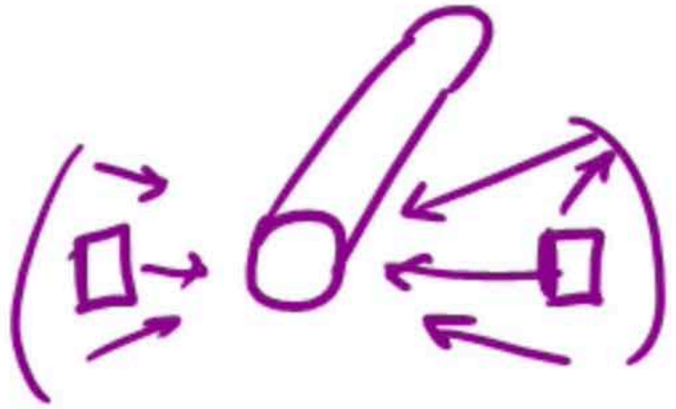
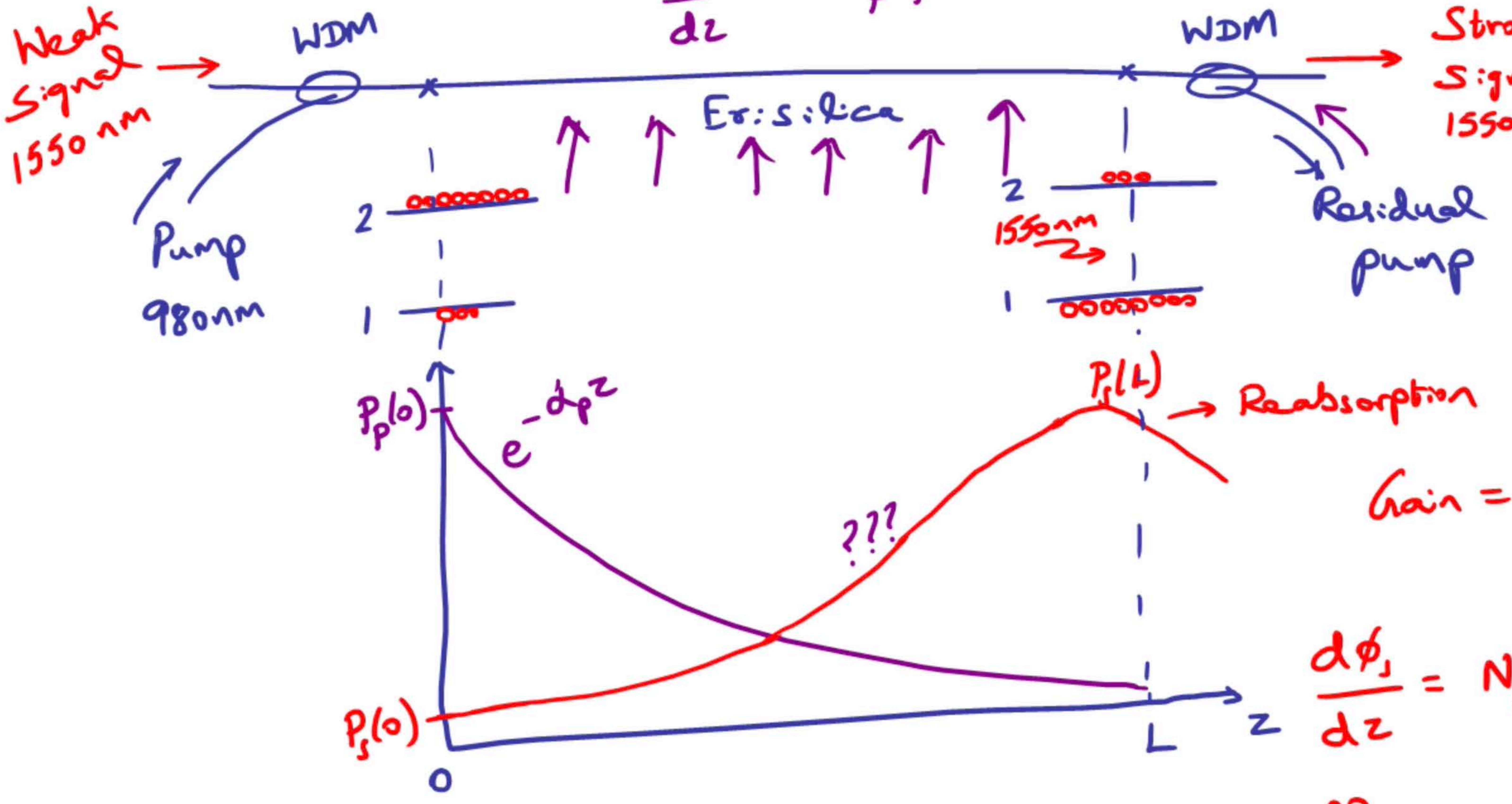
EDFA



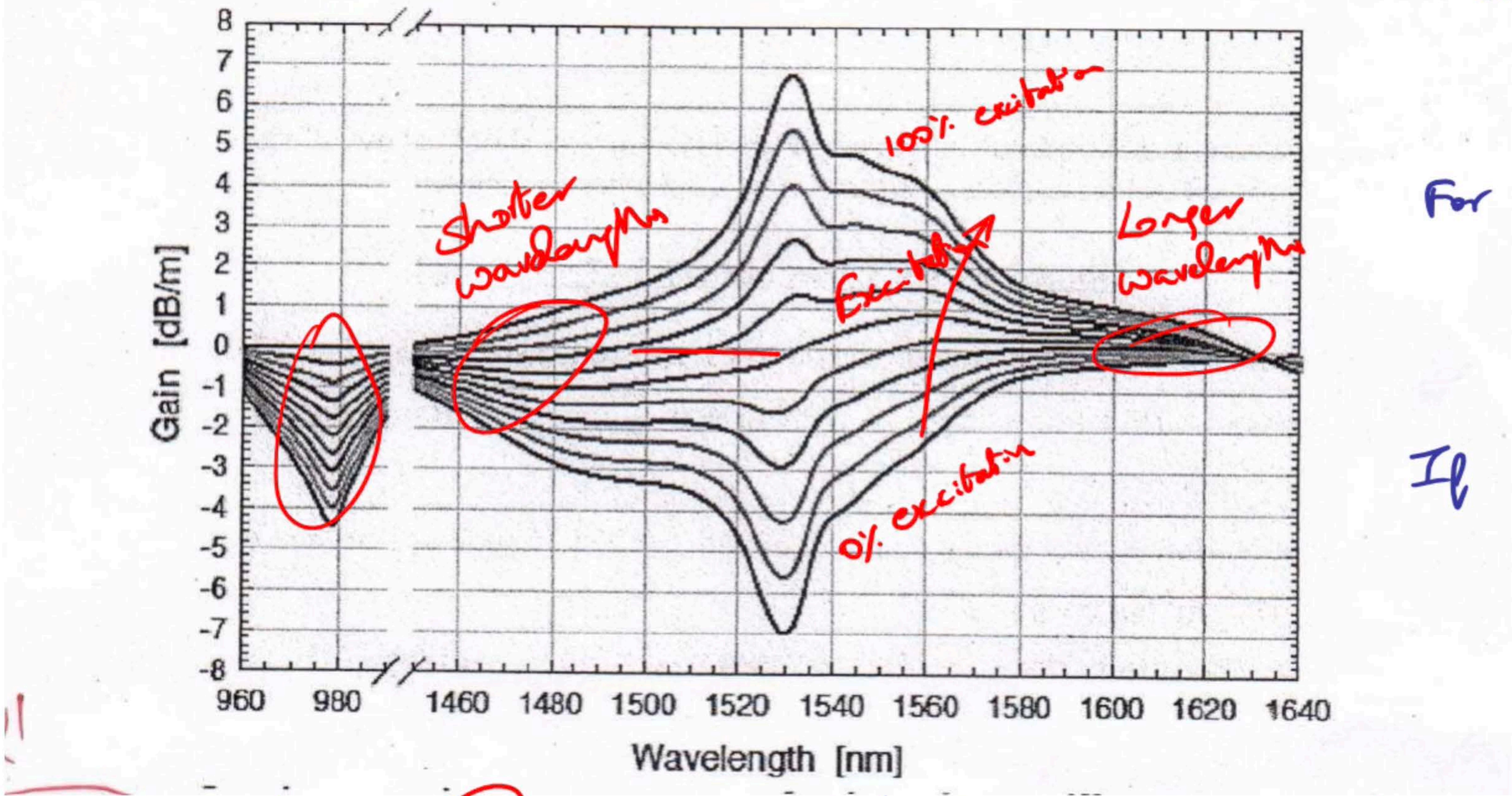
$$\frac{dP_p}{dz} = -\alpha_p P_p$$



$$\text{Gain} = \frac{P_s(L)}{P_s(0)} = \frac{\phi_s(L)}{\phi_s(0)}$$

$$\frac{d\phi_s}{dz} = N_2 \sigma_e^s \phi_s - N_1 \sigma_a^s \phi_s$$

$$P_s = \phi_s \cdot h\nu_s \qquad \frac{dP_s}{dz} = P_s \left[\underline{N_2 \sigma_e^s} - \underline{N_1 \sigma_a^s} \right]$$



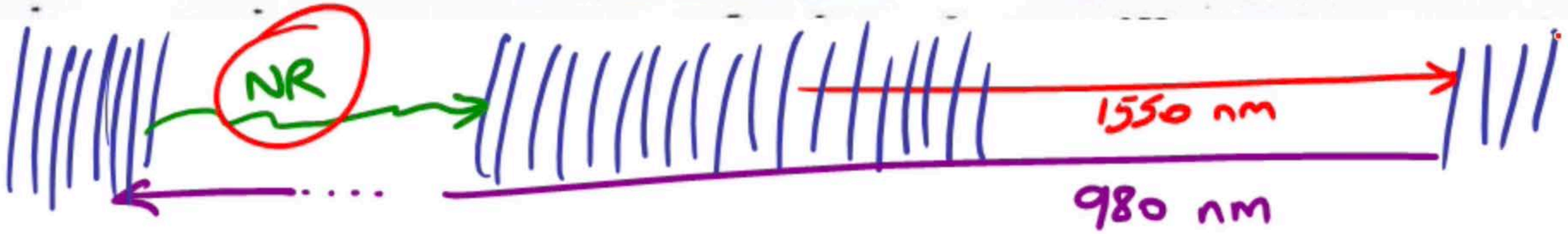
$$G = \frac{P_s(L)}{P_s(0)} = \exp\left[\int_0^L \underbrace{\left(N_2 \sigma_e^s - N_1 \sigma_a^s\right)}_{\text{gain coefficient } \gamma(z)} dz\right]$$

For uniform excitation

$$G = \exp\left[\left(N_2 \sigma_e^s - N_1 \sigma_a^s\right) L\right]$$

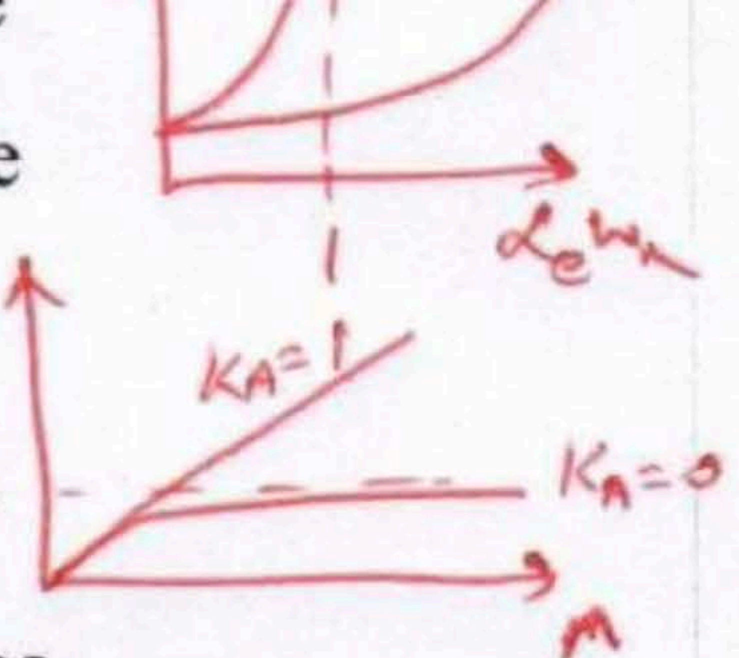
If $\sigma_e^s > \sigma_a^s$, N_2 need NOT be greater than N_1

$\sigma_e^s < \sigma_a^s$, Sufficiently high N_2 over N_1 can provide gain



(a) Asymptotic gain, linear excess noise (b) Asymptotic gain, asymptotic excess noise

(c) Exponential gain, linear excess noise ~~(d)~~ Exponential gain, asymptotic excess noise



$G = \exp\left[\int_0^L \Gamma(\sigma_e^s N_2 - \sigma_a^s N_1)\,dz\right]$

Quantitative Problems (15 points)

$G(dB) = 4.343 \cdot N_a \cdot L \cdot \left[(\sigma_e^s + \sigma_a^s) n_2 - \sigma_a^s\right]$

where $n_2 = \frac{N_2}{N_a}$

& $N_a \simeq N_1 + N_2$

6. Consider the amplification of light at a signal wavelength of 1550 nm in a Er-doped silica optical fiber with a doping concentration of 6×10^{24} m^{-3}. Assume uniform excitation and a pump-signal overlap factor of 0.9 for the Er silica fiber.

   a. Write down the expression for the small signal gain of the amplifier in terms of the fraction of ions in the excited state (n_2) with respect to the total dopant density (N_a) (2 pts)

For $n_2 = 0\%$, $G(dB/m) = -3 = 4.343 \times 6\times10^{24}(-\sigma_a^s) \Rightarrow \sigma_a^s = 1.15\times10^{-25}\ m^2$

   b. The plot below shows the gain spectrum for different values of fraction of ions in the excited state (n_2, lowest curve – 0%, topmost – 100%). Determine the absorption cross-section and emission cross-section at the signal wavelength (4 pts)

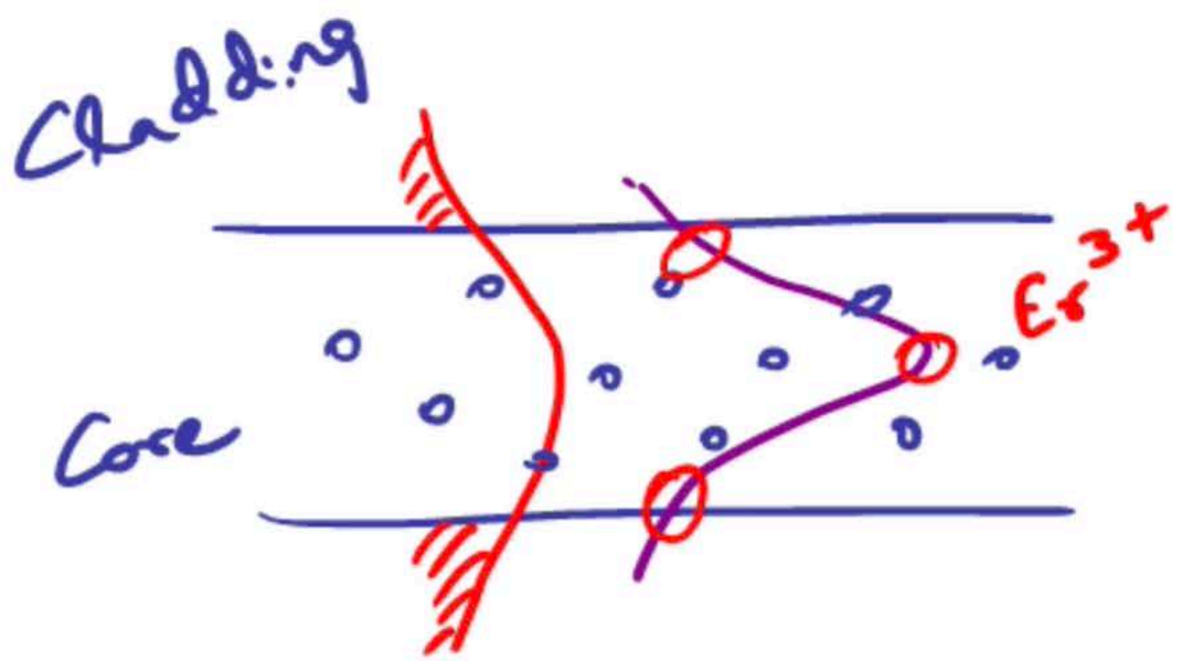
for $n_2 = 100\%$.

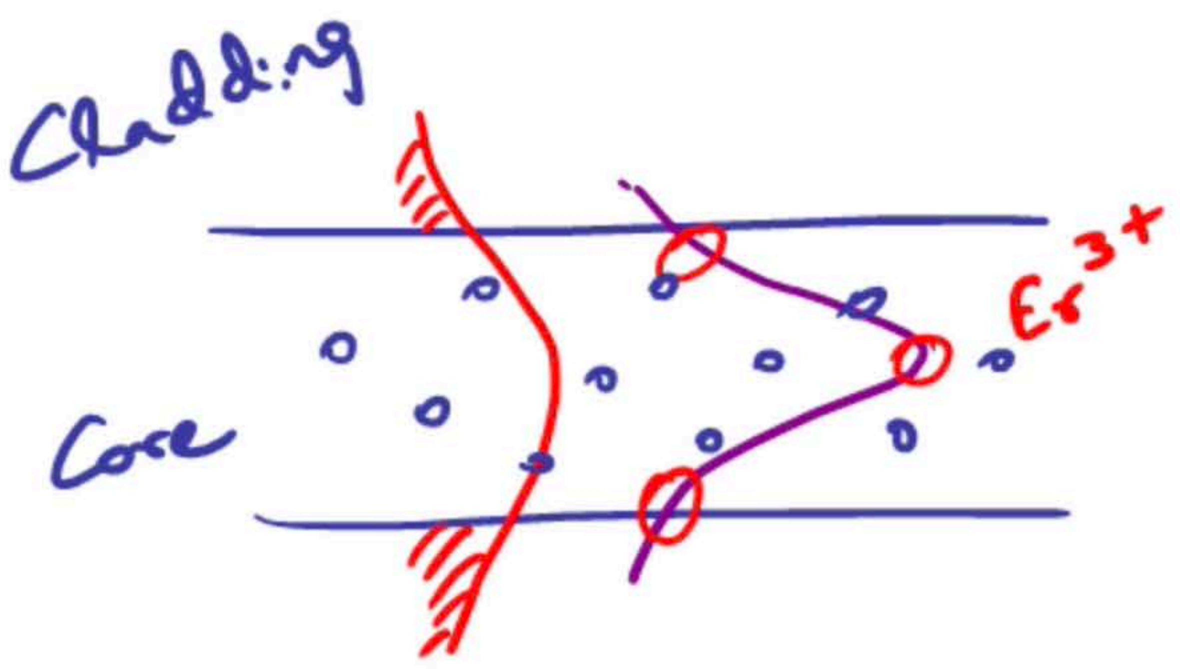
$G(dB/m) = 4 = 4.343 \times 6\times10^{24} \times \sigma_e^s \Rightarrow \sigma_e^s = 1.72\times10^{-25}\ m^2$

   c. Assuming average excitation (n_2) of 60%, what is the length of Er-doped fiber required for achieving a gain of 30 dB? (2 pts)

From the graph @ $n_2 = 60\%$, $G(dB/m) = 1.5 \Rightarrow$ Length reqd. for 30 dB gain $= \frac{30\,dB}{1.5\,dB/m} = \underline{20\,m}$

Pump-signal overlap factor (Γ)





Pump-signal overlap factor (Γ)

Fraction of ions in excited state, $n_2 = \dfrac{N_2}{N_a}$

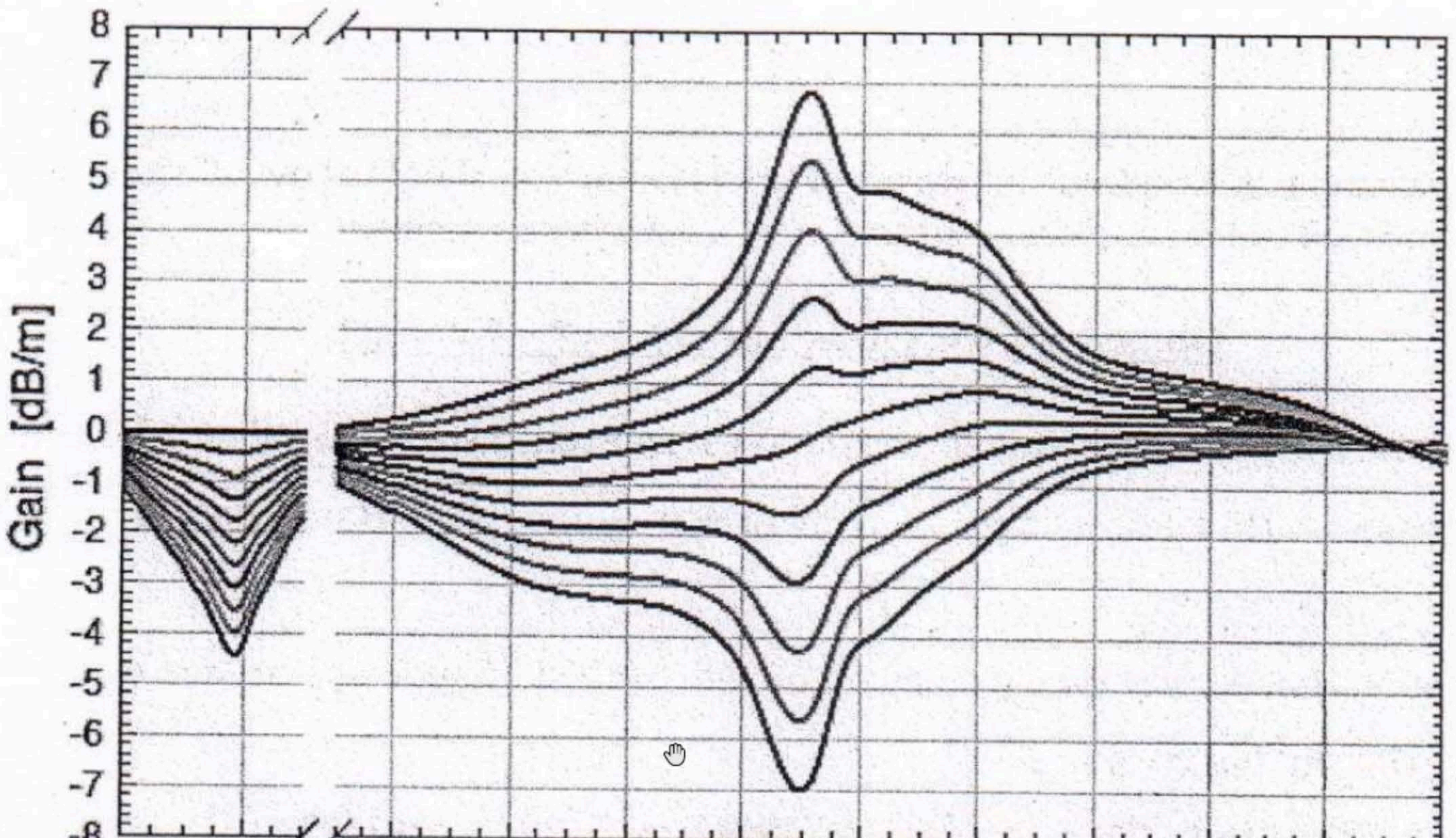
$$\Rightarrow \quad N_2 = n_2 N_a$$

$$N_1 \simeq (1-n_2) N_a$$

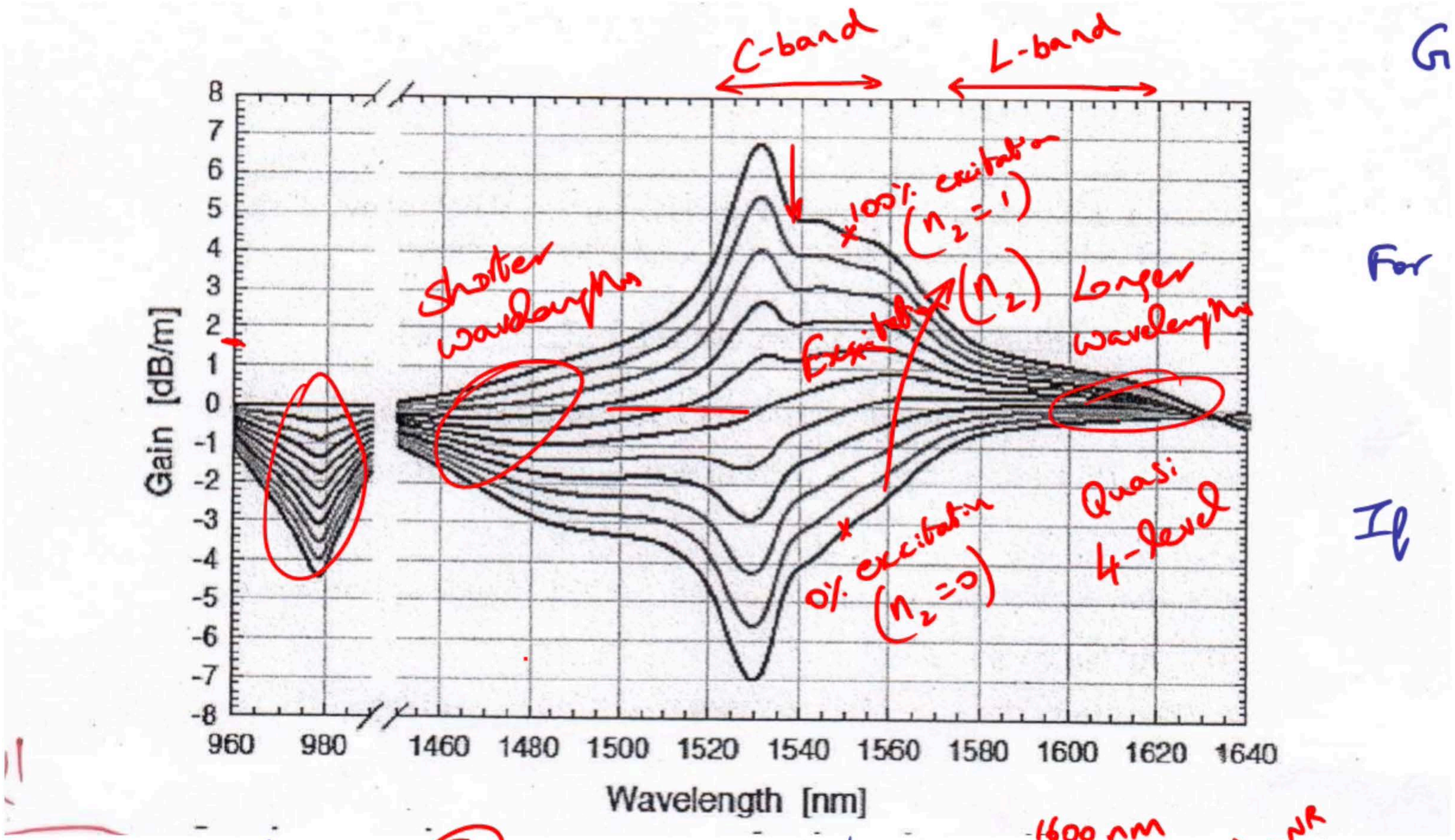
$$G = \exp\left\{ \Gamma \left[n_2 N_a \sigma_e^s - (1-n_2) N_a \sigma_a^s \right] \cdot L \right\}$$

$$G = \exp\left\{ \Gamma L N_a \left[(\sigma_e^s + \sigma_a^s) n_2 - \sigma_a^s \right] \right\}$$

$$G(dB) = 4.343 \times \Gamma L N_a \left[(\sigma_e^s + \sigma_a^s) n_2 - \sigma_a^s \right]$$



Gain [dB/m]
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8



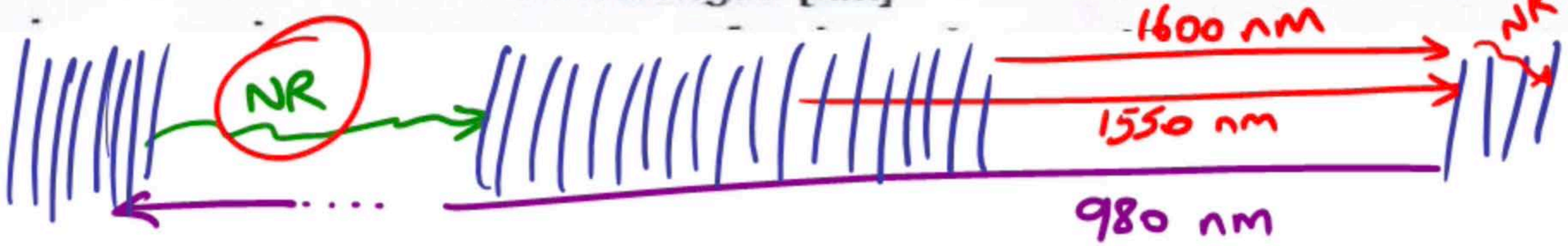
$$G = \frac{P_s(L)}{P_s(0)} = \exp\left[\Gamma \int_0^L \underbrace{(N_2 \sigma_e^s - N_1 \sigma_a^s)}_{\text{gain coefficient } \gamma(z)} dz\right]$$

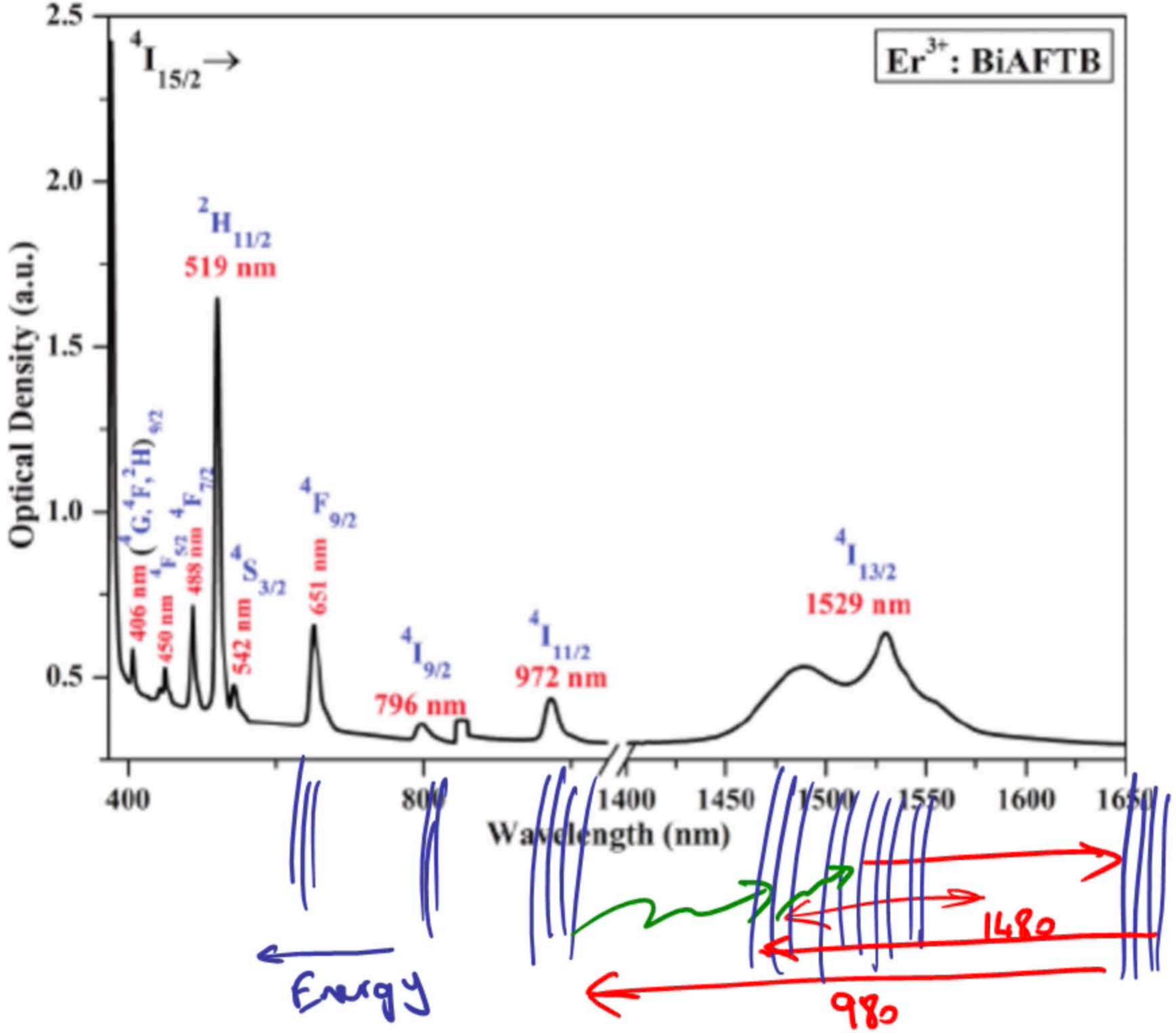
For uniform excitation $N_1(z) = N_1$, $N_2(z) = N_2$

$$G = \exp\left[\Gamma (N_2 \sigma_e^s - N_1 \sigma_a^s) L\right]$$

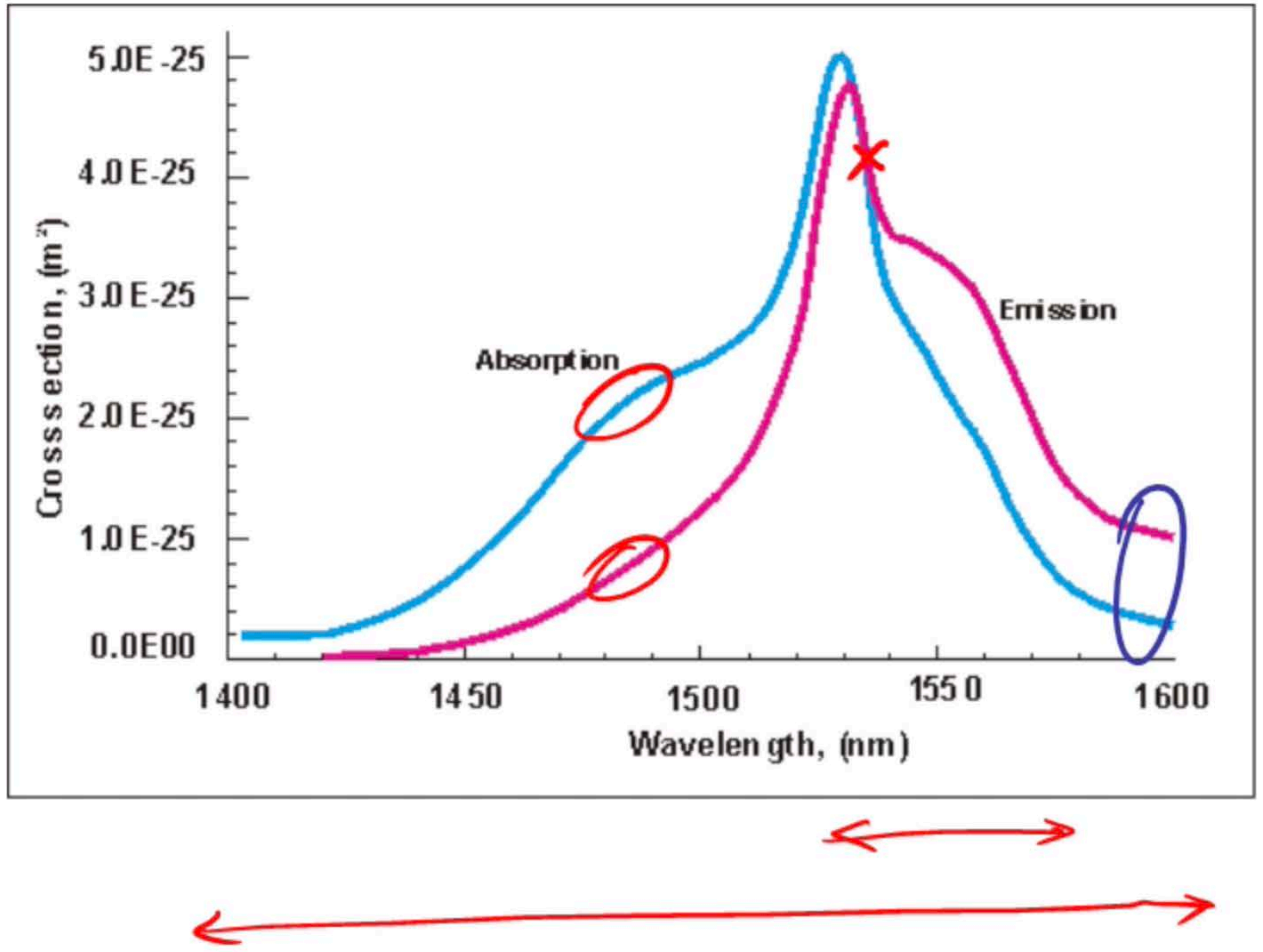
If $\sigma_e^s > \sigma_a^s$, N_2 need NOT be greater than N_1

$\sigma_e^s < \sigma_a^s$, Sufficiently high N_2 over N_1 can provide gain





Er3+: BiAFTB
4I15/2→
Optical Density (a.u.)
Wavelength (nm)
2H11/2
519 nm
4G, 4F, 2H 9/2
406 nm
4F5/2
450 nm
4F7/2
488 nm
4S3/2
542 nm
4F9/2
651 nm
4I9/2
796 nm
4I11/2
972 nm
4I13/2
1529 nm
Energy
1480
980



Cross section, (m²)
Wavelength, (nm)
Absorption
Emission

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