Tutorial 1 – Lasers.

1) a) $\Delta N_0 = \tau N_a W_p$

$\gamma_0 = \sigma . \Delta N_0 = \sigma \tau N_a W_p$

1. b) $W_p = \eta_p \dfrac{P_{pump}}{V N_a h\nu} \Rightarrow \gamma_0 = \underbrace{\sigma \tau}\cancel{N_a}\, \eta_p \dfrac{P_{pump}}{V \cancel{N_a}\, \underbrace{h\nu}}$ I_{sat}^{-1}

Four-level syst : $I_{sat} = \dfrac{h\nu}{\sigma \tau}$

$$\boxed{\gamma_0 = \eta_p \frac{P_{pump}}{V . I_{sat}}}$$

2) $\boxed{\gamma(P) = \alpha_t}$ with $\alpha_t = \alpha - \dfrac{\ln R_2 R_1}{2d}$

$$\boxed{\gamma(P) = \frac{\gamma_0}{1 + P/P_{sat}}}$$

$\dfrac{\gamma_0}{1 + P/P_{sat}} = \alpha_t \Rightarrow \dfrac{\gamma_0}{\alpha_t} = 1 + P/P_{sat} \Rightarrow \boxed{P = P_{sat}\left(\dfrac{\gamma_0}{\alpha_t} - 1\right)}$

$$P = P_{sat}\left(\frac{\gamma_0}{\alpha - \frac{\ln R_1 R_2}{2d}} - 1\right)$$

$$= P_{sat}\left(\frac{2d\gamma_0}{2\alpha d - \ln R_1 R_2} - 1\right)$$

$$= P_{sat}\left(\frac{2d\gamma_0}{\underbrace{2\alpha d - \ln R_2}_{\delta} - \ln R_1} - 1\right)$$

$$\boxed{P = P_{sat}\left(\frac{2d\gamma_0}{\delta - \ln R_1} - 1\right) \text{ with } \delta = 2\alpha d - \ln R_2}$$

$P_{sat} = S . I_{sat}$

2.b) $R_1 \simeq 1 \Rightarrow \ln R_1 = \ln(1 - T_1) \simeq -T_1$

$T_1 \ll 1$ $\qquad (\ln(1+x) \simeq x)$

Taylor expansion

$$P = P_{sat}\left(\frac{2d\gamma_0}{\delta + T_1} - 1\right)$$

Course $\quad P_{out} = \left(\frac{1-R_1}{1+R_1}\right) P \underset{R_1 \simeq 1}{\overset{\uparrow}{=}} \frac{T_1}{2} P$

$$P_{out} = \frac{T_1}{2} P_{sat}\left(\frac{2d\gamma_0}{\delta + T_1} - 1\right)$$

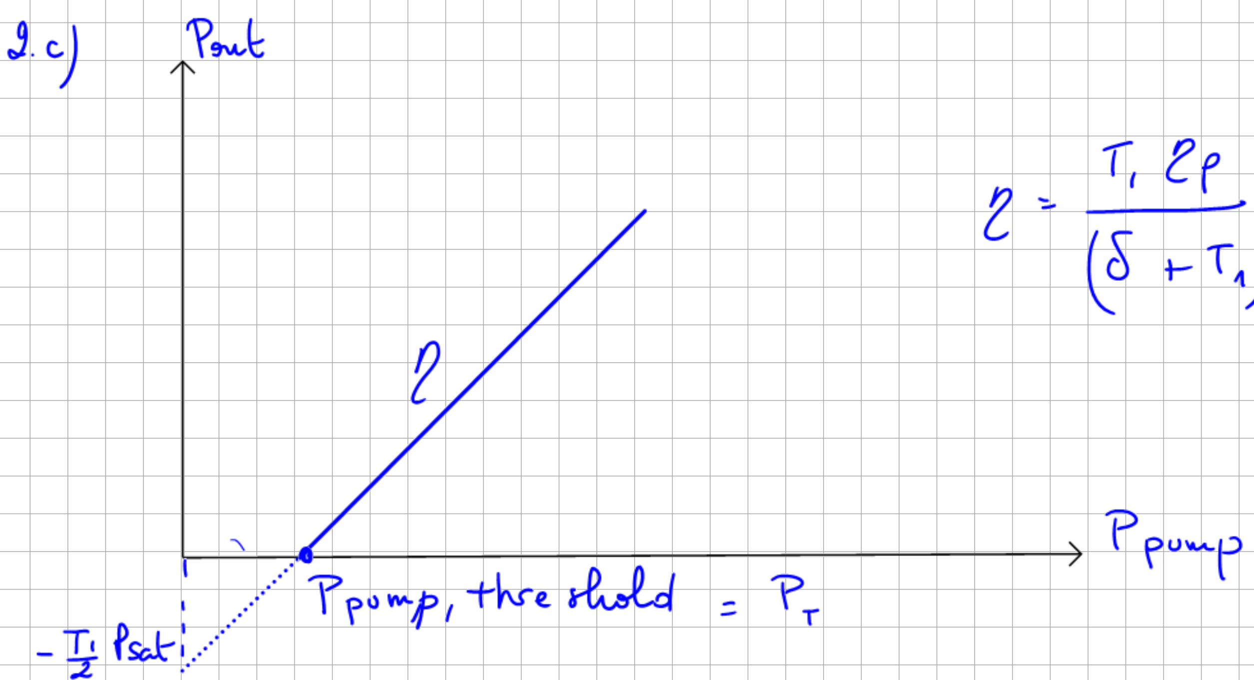
$$\boxed{\gamma_0 = \eta_p \frac{P_{pump}}{V \cdot I_{sat}}}$$ from 1)

Then $\quad P_{out} = \frac{T_1}{2} P_{sat} \cdot \left(\frac{2 \cancel{d} \eta_p P_{pump}}{\underbrace{S \cdot \cancel{d} I_{sat}}_{P_{sat}} (\delta + T_1)} - 1\right)$

$$\boxed{P_{out} = \frac{T_1 \cdot \eta_p}{(\delta + T_1)} P_{pump} - \frac{T_1}{2} P_{sat}}$$

2.c)

$$\eta = \frac{T_1 \eta_p}{(\delta + T_1)}$$



at $P_{pump} = P_T \Rightarrow \alpha_t = \gamma_0$

$\uparrow$

GAIN CONDITION $\geq$

when $P = P_T$ $\quad P_{out} = 0 \Rightarrow \frac{\eta_p P_T}{\delta + T_1} = \frac{P_{sat}}{2}$

$$\boxed{P_T = \frac{(\delta + T_1)}{2\eta_p} P_{sat}}$$

when $(\delta + T_1) \nearrow$ (level of losses) P_T increases too.

3) $I_{sat} = 2.9\ kW/cm^2$

$R_1 = 0.9.$ $\quad \eta_p = 73\%$ $\quad \delta = 0.05$ $\quad \phi = 300\ \mu m.$

$S = \pi \cdot \frac{\phi^2}{4}$

$P_T = 210\ mW.$

$$\eta = \frac{T_1 \eta_p}{\delta + T_1} = 48.6\%$$

$P_{output} = \eta (P_{pump} - P_T) = 0.87\ W.$ for $P_{pump} = 2W$

Exercice 2

1) See Chap 4.

2) $P = P_{sat}\left(\frac{2\gamma_0 d}{\delta + T_1} - 1\right) \Rightarrow P_{out} = \frac{T_1}{2} P$ (R_1 close to 1)

$$P_{out} = \frac{T_1}{2} P_{sat}\left(\frac{2\gamma_0 d}{\delta + T} - 1\right)$$

$\frac{\partial P_{out}}{\partial T_1} = 0 \rightarrow$ Max of P_{out}

$$\rightarrow \boxed{T_{1,opt} = -\delta + \sqrt{2\gamma_0 d \delta}}$$

$$\boxed{P_{out,opt} = \frac{P_{sat}}{2\delta}\left(\sqrt{2\gamma_0 d\delta} - \delta\right)^2}$$

When γ_0 is high then $T_{1,opt}$ is high. It means that you can use M_1 with a small R_1

The higher is γ_0, the smaller is optimized R_1

3) $T_1 = 21,6\%$ $\Rightarrow$ $\boxed{R_1 = 78,4\%}$

$P_{out} = 271\ W$