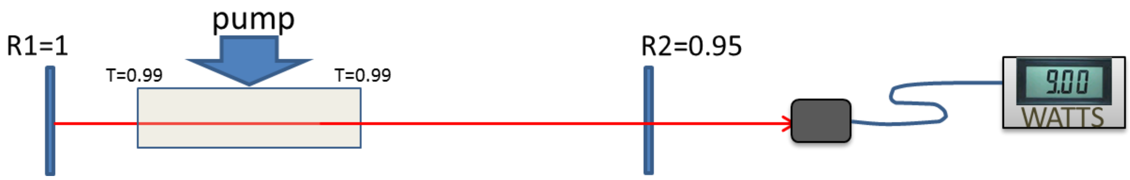
PHYC 569, Advanced Topics in Modern Optics

(Laser Physics II: PHYC/ECE 564)

Fall 2016

Homework #1, Due Tuesday Sept. 6

1. Consider the laser system below with an output power measured at 9 Watts. The beam radius inside the gain medium is w~100 μm.



a. What is the threshold integrated gain (g_{th})? 1 points

$R_1R_2T^4e^{g_{th}} = 1$, thus $g_{th} \approx 1 - R_2T^4 \approx 1 - T^4 + T_2$=0.088

b. Estimate the (total) power inside the gain medium. (Assume high-Q cavity) 1.5 points

$P_{inside} = P^+ + P^- \sim 2P^+ = \frac{2P_{out}}{T_2} = \frac{2P_{out}}{1-R_2} = 18/.05$=360 W. P^+=180W

c. This output power (9 W) is obtained when pumped 6-times above threshold. What is the saturation intensity I_s of the gain medium? 2 points

$\frac{g_{th}}{g_0} = \frac{1}{1+\frac{2P^+}{P_{sat}}} = \frac{1}{6}$, find P_{sat} (P_{sat}=360/5=72W)

Also, $g_0 \approx 6g_{th} \approx 0.53$

d. Is the output coupling optimum? If not, what is the optimum output coupling and what would be the maximum output power? 3 points

$$P_{out} = T_2\frac{P_{sat}}{2}\left(\frac{g_0}{g_{th}} - 1\right) = T_2\frac{P_{sat}}{2}\left(\frac{g_0}{-\ln(R_1R_2T^4)} - 1\right) \approx T_2\frac{P_{sat}}{2}\left(\frac{g_0}{1 - T^4 + T_2} - 1\right)$$

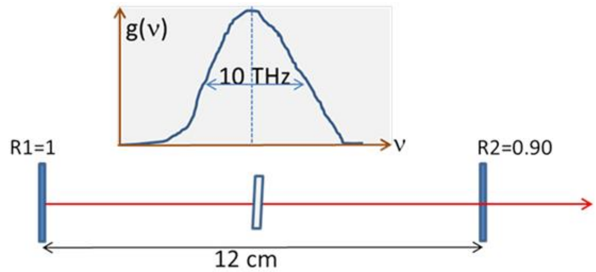
Optimum T_2 is by finding the maximum of $T_2\left(\frac{g_0}{1-T^4+T_2} - 1\right)$;

$T_2^{opt} = -(1-T^4) + \sqrt{(1-T^4)g_0} \approx 0.1$ (or 10%). Thus, 5% is not optimum output coupling

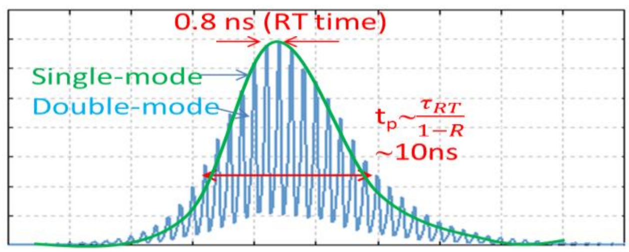
e. The spontaneous emission (fluorescence) from the sides of the gain medium is also monitored. If we block the cavity to stop lasing, what happens to the intensity of the fluorescence and why? Quantify your answer. 2.5 points

Fluorescence power is $P_f \propto A_{21} \times N_2 = A_{21}\frac{N_2^0}{1+\frac{2P^+}{P_{sat}}}$, when cavity blocked, P^+=0, and fluorescence gets enhances by factor $1 + \frac{2P^+}{P_{sat}}$=6

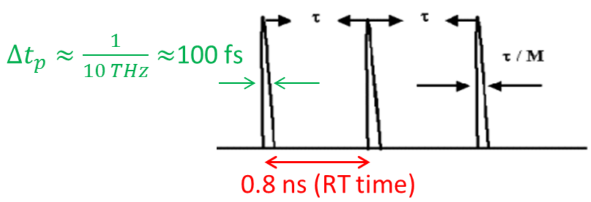
2. Consider the laser system shown:



a. If Q-switched, approximately sketch the pulse shape assuming two cases of (i) one and (ii) two longitudinal modes? Be semi-quantitative on your time-axis. 2.5 points



b. If cw- modelocked, approximately sketch the pulse train assuming the shortest pulse. How many longitudinal modes will oscillate? Be semi-quantitative on your time-axis. 2.5 points



Number of modes=(0.8x10^{-9}) /(100x10^{-15}) ~8000

c. Considering that the refractive index is wavelength dependent in the gain medium and cavity optics, what do we need to do to ensure the shortest possible pulse? Explain. 2.5 points

In the presence of group-velocity dispersion (GVD, usually >0) in the gain medium and cavity optics, the pulses will be broadened. To obtained the shortest possible pulse (bandwidth limited pulses) one needs to add additional intracavity dispersive elements with opposite GVD sign (e.g. prism pairs or chirped dielectric mirrors) to make total round-trip GVD~0

d. Consider a Yb^{3+} fiber amplifier at λ=1030 nm with a diameter of D=100 μm and length L_g= 1 meter. The concentration of Yb is N_0= 1.5×10^{20} cm^{-3} and upper state lifetime τ_2=3 ms. What is the maximum power that can be extracted from this laser (i.e. the maximum P_{out}-P_{in})? Explain your answer. 2.5 points

Gain volume=(100 μm)^2 ×1m=.01 cm^3, therefore, the total atoms (ions) that can be excited N^{total}=<1.5×10^{18}. Each excitation can give a photon of energy E=1.24/1.03 eV~1.93×10^{-19}J. Each atom can be recited once in a lifetime τ_2=3ms, thus the maximum power that can be extracted is P=N^{total}×E/τ_2~96.30W~100W