Solutions

OPTICAL SCIENCE & ENGINEERING
University of New Mexico

Laser Physics I (PHYC/ECE 464)

FALL 2006

Midterm Exam, Closed Book, Closed Notes

Time: 5:30 - 6:45

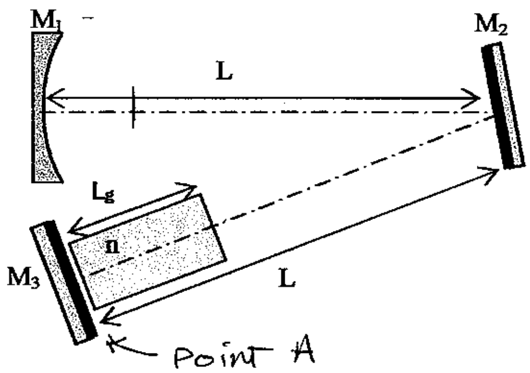
NAME ....Sheik Bahae.... ....
last *first*

grade

Total= 100 points

Please staple and return these pages with your exam.

1. Consider the laser cavity (shown below) consisting of two flat mirrors and one concave mirror or radius **R**. The gain medium of length $\mathbf{L_g}$ and index **n**, is placed right next to the flat mirror M_3.

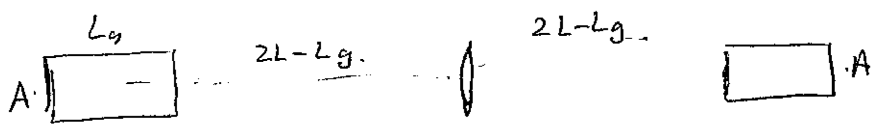


(a) Identify an appropriate round-trip unit cell (for your choice of the starting point) and then describe the procedure to obtain the cavity ABCD matrix. (do not perform the matrix multiplication). *(15 pts.)*

(b) Assuming the cavity ABCD is known (from part a), how will you find the beam parameter (q) at mirror M_2? *(10 pts.)*

(c) Where is the location of the beam waist w_0? Give w_0 in terms of the cavity ABCD of part (a) and wavelength λ_0 *(10 pts.)*

(a) starting from point A (The Best choice!).



$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} 1 & \frac{L_g}{n} \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 2L-L_g \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ -\frac{2}{R} & 1 \end{pmatrix}\begin{pmatrix} 1 & 2L-L_g \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & \frac{L_g}{n} \\ 0 & 1 \end{pmatrix}$$

(b)
$$q(\text{at } A) = \frac{A + B\,q(\text{at } A)}{C + D\,q(\text{at } A)}$$
find q (at A).

Then
$$q(M_2) = \frac{A_1 + B_1\,q(\text{at } A)}{C_1 + D_1\,q(\text{at } A)}$$

where
$$\begin{pmatrix} A_1 & B_1 \\ C_1 & D_1 \end{pmatrix} = \begin{pmatrix} 1 & L-L_g \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & \frac{L_g}{n} \\ 0 & 1 \end{pmatrix}.$$

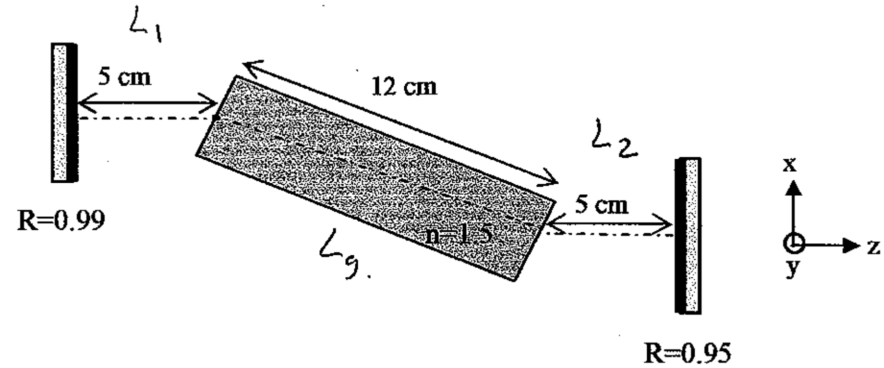
(c) From part a)

$$\frac{1}{q(ATA)} = \frac{1}{R \to \infty}{}^{0} - \frac{i\lambda_0}{\pi W_0^2}$$

2.

(a) Estimate the photon lifetime of the passive cavity shown below, for the polarization that has the least loss. What is this polarization (x, y, z or a combination of these)?
(The ends of the rectangular block are tilted at 56.31° with respect to vertical.) *(15 pts.)*

(b) This cavity is to be used as a scanning Fabry-Perot interferometer for λ_0=0.5 μm (linearly polarized along the direction obtained in part a). Quantitatively, plot its transmission versus the end-mirror displacement Δd (for a range of 0.75 μm). *(15 pts.)*



a). Polarization is along x (P-pol.) for Brewster angle

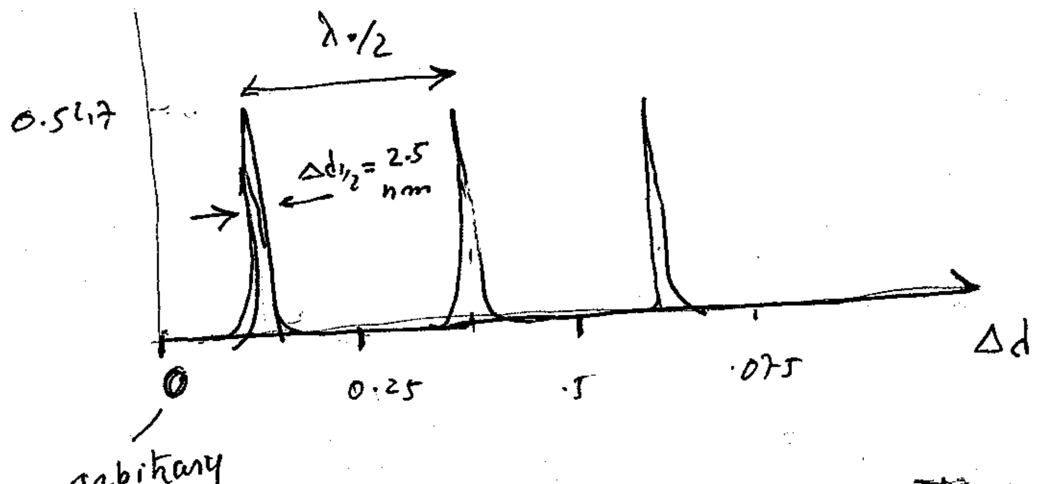
$$\tau_p = \frac{\tau_{RT}}{1-S} \qquad S = R_1 R_2$$

$$\tau_{RT} = \frac{2 L_g n}{c} + \frac{2(L_1+L_2)}{c} = \frac{2}{3\times 10^{10}}\left[\frac{12\times 1.5}{} + 10\right]$$

$$= \frac{2\times 28}{3}\times 10^{-10} \approx 1.8 \text{ ns.}$$

$$\tau_p = \frac{1.8}{1-0.99\times 0.95}$$

(b)



$$\Delta d_{FSR} = \frac{\lambda_0}{2} = 0.25 \text{ um}$$

$$\Delta d_{1/2} = \frac{\lambda_0}{2}\times\frac{1}{\mathcal{F}}$$

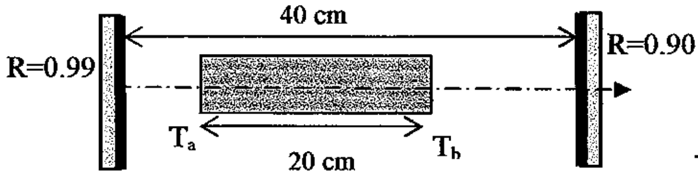
$$\mathcal{F} = \frac{\pi\sqrt[4]{R_1R_2}}{1-\sqrt{R_1R_2}} \approx \frac{1}{1-S} \approx 100$$

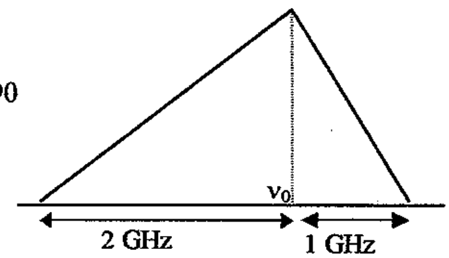
$$T_{max} = \frac{(1-R_1)(1-R_2)}{(1-\sqrt{R_1R_2})^2} \approx 0.517$$

3. The *inhomogeneous* lineshape function for the laser shown below can be approximated by a triangle as shown on the right. Furthermore, $A_{21}=2.5\times10^{6}\ s^{-1}$; $g_2=3$; $g_1=1$; $\nu_0=12{,}500\ cm^{-1}$; *and n(gain medium)=1.5* The gain medium facets are AR-coated but still have a residual reflection (loss) of 0.5% per surface at $\nu\approx\nu_0$. Use the above information to compute:

(a) Stimulated emission cross section at ν_0. *(10 pts.)*

(b) The threshold population inversion $(N_2-g_2/g_1N_1)_{th}$. *(10 pts.)*





a) $\sigma(\nu_0) = A_{21}\dfrac{\lambda_0^2}{8\pi n^2}\, g(\nu_0)$ $\lambda = \dfrac{1}{12{,}500\ cm^{-1}} = 0.8\ \mu m$

$g(\nu_0) = \dfrac{1}{GHz(1+2)\times\frac{1}{2}} = \dfrac{2}{3}\times10^{-9}$ sec.

$\sigma(\nu_0) = 2.5\times10^{6}\times\dfrac{(0.8\times10^{-4})^2}{8\pi(1.5)^2}\times\dfrac{2}{3}\times10^{-9}$.

b) $S\, e^{-2 l_g \sigma (N_2 - \frac{g_2}{g_1}N_1)_{th}} = 1$. $S = R_1R_2T_a^2T_b^2$

$\left(N_2 - \dfrac{g_2}{g_1}N_1\right)_{th} = -\dfrac{1}{2l_g\sigma(\nu_0)}\ln\dfrac{1}{S}$

4. ***Briefly*** **yet** ***clearly*** **(in less than 30 words, and using drawings where needed)** answer **only one** of the following **2** questions. (15 pts.)

(a) In a CW laser, why does the gain saturate at slightly below the loss level? What fundamental limitation does this process impose on the output characteristic of the laser?

(b) Briefly describe the homogenous and inhomogeneous broadening in a laser medium. Give two examples for each case.

a) Schawlow – Townes limit (spont. Emission)

b) Read the text