University of Technology

Department of Laser & Opto-electronic Engineering

Final Examination 2011-2012

Subject: Laser Systems	***Class: 3^{rd} year***
Division: Laser Physics	***Time:3 hours***
Examiner: Dr. Hisham M. Ahmed	***Date:27/5 /2012***

Answer five questions only

Q1: A. A 25 mW HeNe laser (λ = 632.8 nm) with an effective output aperture diameter of 1.5 mm. If the laser beam travels 10 m to a positive lens having a focal length of 3 cm. Find:

(8 Marks)

i- beam divergence.
ii- beam diameter at the lens.
iii- beam diameter of focused spot.
iv- Power density before the lens.
v- Irradiance of the focused spot.

B- Compare between the influence of the input power on the output power of a CW laser and that of a pulsed laser. Draw figures to assist your answer. **(4 Marks)**

Q2: A. An argon ion laser is operating at 488 nm in a confocal cavity in the TEM_{00} mode with a mirror separation of 0.6 m. Assume that the gsin medium is 0.4 m long, the beam radius (the effective limiting aperture) for the laser beam is 0.5 mm at each mirror, and the only losses in the cavity are the diffraction losses given by the following table. What must the gain coefficient be for the laser to operate at threshold with mirror reflectivities of 99.99% at the laser wavelength?

(8Marks)

N	**Internal losses**
1	**0.0008**
0.85	**0.0025**
0.70	**0.01**

B- What are the roles of the optical cavity of a laser? **(4 Marks)**

Q3: A. An Nd : glass laser (n=1.5) has a laser rod of 0.2m long and the laser mirrors are very close to he ends of the rod. Suppose there are no losses except that of the mirrors whose reflectivities are 100% and 90% respectively, and 150 longitudinal modes are oscillating in this laser. Compare between the pulse duration if this laser is: **(8 Marks)**

i. Q-switched
ii. Cavity dumped.
iii. Mode locked.

(اقلب الصفحة رجاءاً)

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B- Why lasers with high gain media are not necessarily have high efficiencies? **(4 Marks)**

Q4: A. Show that the threshold gain coefficient could be given as:

$$K_{th} = \alpha + \frac{1}{2L} \ln(1/R_1R_2)$$

(6 Marks)

B. The gain of a He-Ne laser is 10 times the threshold value of $0.04 m^{-1}$ at 632.8nm and the internal loss per pass is 0.5%. For a laser cavity length of 0.2m, compute the optimum mirror coupling transmission.

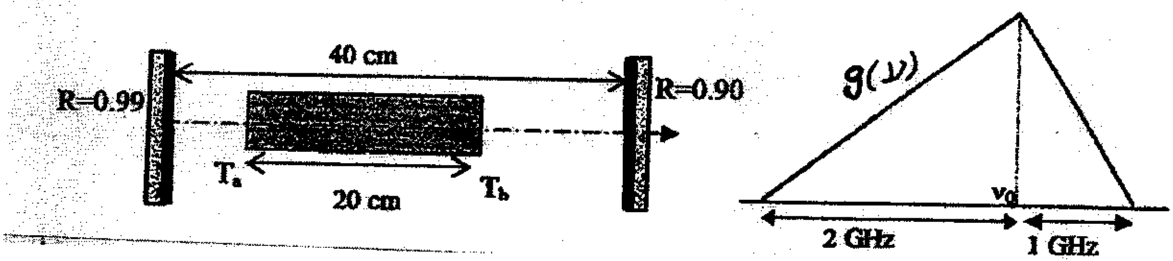
(6 Marks)

Q5: A. The inhomogeneous lineshape function for the laser shown below can be approximated by a triangle as shown on the right. Furthermore, $A_{21}=2.5 \times 10^6 s^{-1}$, $g_3=3$, $g_1=1$, $\upsilon_o=12500 cm^{-1}$, and n (gain medium)=1.5. The gain medium facets are AR-coated but still have a residu reflection (loss) of 0.5% per surface at $\upsilon = \upsilon_o$. Use the above information to compute:

a. Stimulated emission cross section at υ_o.

b. The threshold population inversion $(N_2-(g_2/g_1)N_1)_{th}$.

(8 Marks)



B-What physical processes result in homogenous broadening? Inhomogeneous broadening?

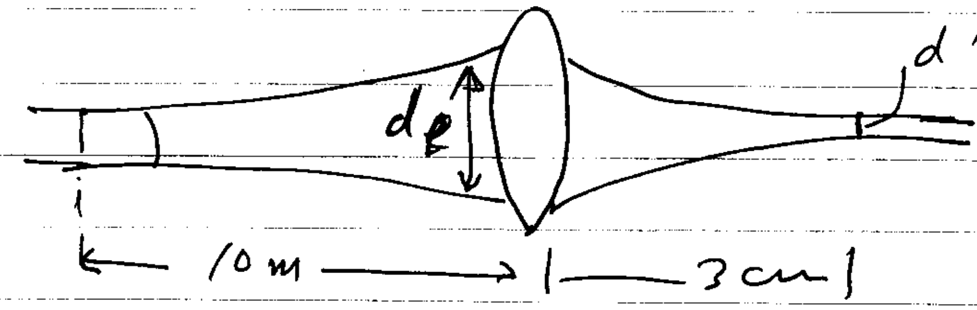
(4 Marks)

Q6: A. Compare between the Q-switching and cavity dumping mechanism. **(6 Marks)**

B. To design an Ar^+ laser (λ=514.5) having a beam diameter of 0.5 mm located at the center of the laser cavity and the distance between the mirrors is 1 m. What kind of mirrors should be used?

(6 Marks)

Q1) A -



(i) $\theta = \frac{2\lambda}{\pi(\frac{d}{2})} = \frac{2 \times 632.8 \times 10^{-9}}{\pi\left(\frac{1.5 \times 10^{-3}}{2}\right)} = 536 \times 10^{-6}$ rad

$= 0.536$ mrad

(ii) $d_\ell = l\theta + d = 10 \times 536 \times 10^{-6} + 1.5 \times 10^{-3}$

$= 6.86 \times 10^{-3}$ m.

(iii) $d' = f\theta = 3 \times 10^{-2} \times 536 \times 10^{-6}$

$= 0.0161 \times 10^{-3}$ m.

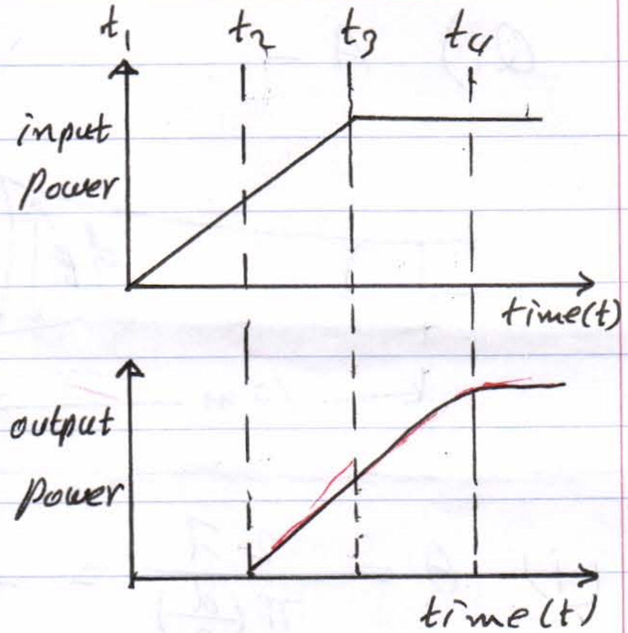
(iv) $I = \frac{P}{\Delta S} = \frac{25 \times 10^{-3}}{\pi\left(\frac{6.86 \times 10^{-3}}{2}\right)^2}$

$= 6.76 \times 10^{2}$ W/m^2

(v) $I = \frac{P}{\Delta S} = \frac{25 \times 10^{-3}}{\pi\left(\frac{0.0161 \times 10^{-3}}{2}\right)^2} = 1228 \times 10^{5}$ W/m^2.

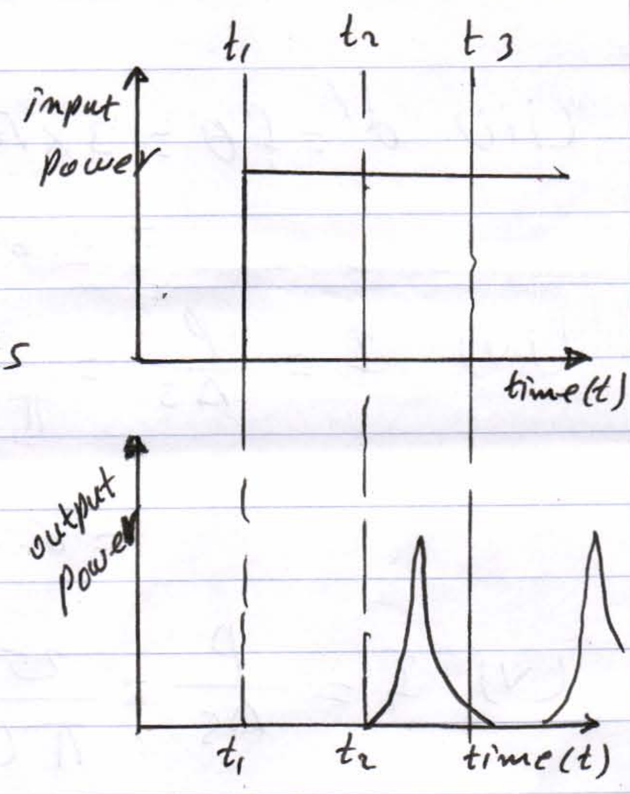
Q # -

B- For a CW laser:



At time t_1 the excitation mechanism is activated. Ther i's no output power.
At time t_2, lasing starts and output power of the laser start to increase.
At time t_3 the input power reaches its steady state (constant input power). Output power from the laser continues to rise, until t_4, when it reaches its steady state value -

For a pulsed laser:



Starting from t_1, contineous strong pumping but there is no laser output.
At times t_2, lasing starts but the output power has not reach the saturation value that cause hole burning in the gain curve.

Q2

~~Ans~~: A – $N = \frac{a^2}{\lambda L}$

$= \frac{(0.0005)^2}{488\times10^{-9}(0.6)} = 0.85$

From the table : internal losses $= 0.0025$.

$K_{th} = \frac{1}{2\ell}\ln\left[\frac{1}{R_1R_2(1-S)^2}\right] + \alpha$

$\because \alpha = 0$ (no absorption losses)

$\therefore K_{th} = \frac{1}{2(0.4)}\ln\left[\frac{1}{(0.9999)^2(1-0.0025)^2}\right]$

$K_{th} = 6.5\times10^{-3}\ m^{-1} = 0.0065\ m^{-1}$

B –

1 – It provides the positive feedback that turns an amplifier into an oscillator.

2 – determines the properties of the beam of light that is emitted by the laser. This beam is characterized by its transverse and ~~longitudinal~~ longitudinal mode structure.

Q3

B –

(i) $\Delta t_{1/2} = t_c = \frac{2nL}{c(1-R_1R_2)} = \frac{2\times 1.5\times 0.2}{3\times 10^8(1-1\times 0.9)}$

$= 2$

(ii) $\Delta t_{1/2} = \frac{2nL}{c} = \frac{2\times 1.5\times 0.2}{3\times 10^8} = 0.2\times 10^{-8}\ s = 2$

(iii) $\Delta t_{1/2} = \frac{1}{N\Delta\nu_{MS}} = \frac{2nL}{Nc} = \frac{0.2\times 10^{-8}}{150} = 1.33\times 10^{-11}\ s$

$= 13.3\ ps$ -

This means that :

in a Q-switching technique : short pulses are produced ($\Delta t_{1/2} = 20\ ns$)

in cavity dumping technique : very short pulses are produced ($\Delta t_{1/2} = 2\ ns$)

in Mode locking technique : the shortest pulses are produced ($\Delta t_{1/2} = 13.3\ ps$)

Q3) B – The actual value of the gain depends on the population inversion and on the physical properties of the medium according to:

$$K = \Delta N \sigma_e$$

while the efficiency, expressed as the ratio of laser light output power to input pumping power, depends on how effectively the pump power is converted into a population inversion, on the probabilities of the different kinds of transitions from the upper energy level and on the losses in the system.

Q4) A —

$$G_L = 1 = R_1 R_2 M (G_0)_{th}^2$$

$$1 = R_1 R_2 e^{-2\alpha L} \cdot e^{2K_{th} L}$$

$$1 = R_1 R_2 e^{2(K_{th} - \alpha) L}$$

$$\frac{1}{R_1 R_2} = e^{2(K_{th} - \alpha) L}$$

$$2(K_{th} - \alpha) L = \ln \frac{1}{R_1 R_2}$$

$$K_{th} - \alpha = \frac{1}{2L} \ln \frac{1}{R_1 R_2}$$

$$K_{th} = \alpha + \frac{1}{2L} \ln \frac{1}{R_1 R_2}$$

B —

$$T_{opt} = (K_o L S)^{1/2} - S$$

$$K_o = 10 \times K_{th} = 10 \times 0.04 = 0.4 \, cm^{-1}$$

$$\therefore T_{opt} = (0.4 \times 0.2 \times 0.005)^{1/2} - 0.005$$

$$= 0.015$$

$$\therefore R_{opt} = 1 - T_{opt} = 1 - 0.015$$

$$= 0.985$$

$$= 98.5\%$$

Q5) A –

$$\sigma_e(\nu_0) = \frac{(\lambda_0/n)^2}{8\pi \tau_{sp}} g(\nu) = A_{21} \frac{\lambda_0^2}{8\pi n^2} g(\nu_0)$$

$$g(\nu_0) = \frac{1}{\frac{1}{2}(1+2)\,GHz} = \frac{2}{3} \times 10^{-9} s \;,\; \lambda = \frac{1}{12500\,cm^{-1}} = 0.8\,\mu m$$

$$\therefore \sigma_e(\nu_0) = 2.5 \times 10^{6} \times \frac{(0.8 \times 10^{-4} cm)^2}{8\pi (1.5)^2} \times \frac{2}{3} \times 10^{-9} = 0.0188 \times 10^{-11}\, cm^2$$

$$\Delta N_{th} = (N_2 - \frac{g_2}{g_1} N_1)_{th} = \frac{\ln 1/R_1 R_2 T_a^2 T_b^2}{2 \sigma_e l}$$

$$= \frac{\ln 1/(0.99)(0.9)(0.005)^2(0.005)^2}{2 \times 0.0188 \times 10^{-11} \times 20}$$

$$= 28.336 \times 10^{11}\, cm^{-3}$$

B –

Q6)

A-

Q - Switching	Cavity Dumping
1- short pulses (tens of ns)	1- very short pulses (few ns)
2- The pulse length produced depends on the active medium	2- The pulse length produced depends on the length of the laser ($\Delta t_{1/2} = 2L/C$)
3- Work with those lasers in which the upper energy level has long lifetime	3- Work with any laser
4- the Q-switching is a rapid switching between the close (on) and open (off) position	4- the cavity dumping is a switching between the open (off) and the close (on) positions

B/ Since the beam diameter is located at the center of the laser cavity then this laser has two concave mirrors of equal radius of curvature.

i.e. $R_1 = R_2$, $Z = L/2 = 1/2 = 0.5\ m$

$$R(Z) = Z\left[1 + \left(\frac{\pi W_0^2}{\lambda Z}\right)^2\right]$$

$$= 0.5\ m\left[1 + \left(\frac{\pi(2.5\times10^{-4}\ m)^2}{514.5\times10^{-9}\times0.5}\right)^2\right]$$

$$= 0.79\ m = 79\ cm$$

∴ We will use two concave mirrors each of radius of curvature $\simeq$ 80 cm.