University of Technology
Department of Laser & Opto-electronic Engineering
Final Examination 2011-2012

Subject: Laser Design | *Class: 4^{th} year*
Division: Laser Engineering | *Time:3 hours*
Examiner: Dr.Mohammed Jalal | *Date: 28/ 5 /2012*

Answer five questions only

Q_1: For a Q-switching Nd:YAG laser oscillator featuring a negative branch unstable resonator with length (L=125cm) and a magnification of (4) as shown in fig.1:

a- Explain the effect of the contribution of the aperture (d) and mirror (M_1) on the resonator field.

b- Calculate the beam diameter inside the laser rod.

(12 Marks)

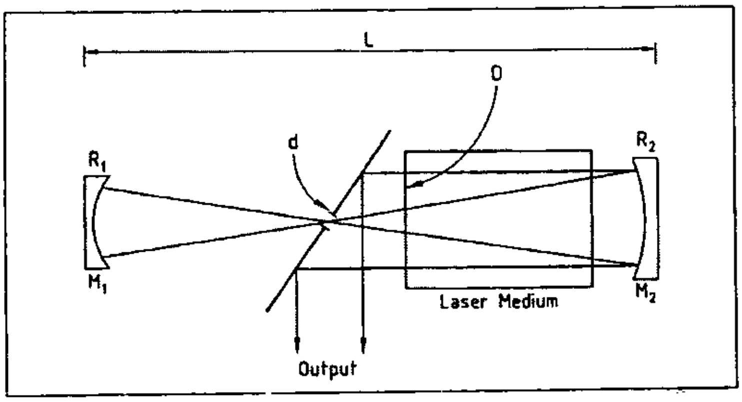

Fig.1. Schematic of Q-switching Nd:YAG laser oscillator.

Q_{2A}: Explain two mechanisms that lead to lamp explosion and two mechanisms that result in long-term degradation of the optical output from a lamp.

(4 Marks)

Q_{2B}: A CW Nd:YAG laser with a total power absorbed in the laser rod of (216W) requires a cooling system which will limit the temperature rise in the rod coolant to (4°C). Design and draw a cooling system which satisfies this condition and make the laser give an output power of (14W). Note that the total heat to be dissipated in coolant is 786W, and typical cooling temperature is (40°C). **(8 Marks)**

Q_{3A}: A nearly hemispherical He-Ne laser resonator with a mirror separation of (50cm) has a micrometer adjustment to vary the separation between the flat mirror and the output mirror of radius of curvature R_2=50cm, such that ($L=R_2-\Delta_L$) (where $\Delta_L \ll R_2$). If spot size between 1 and 2mm are desired for the output beam, over what range must the mirror separation vary?

(6 Marks)

(اقلب الصفحة رجاءاً)

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Q_{3B}: An end-pumped Nd:YVO_4 laser crystal $(3\times3\times3mm)$ was pumped with a fiber-coupled laser-diode array. The output from the fiber bundle was imaged onto the crystal surface into a pump spot radius of (0.4mm). Assume that the pumping beam induces a thermal lens of focal length (f) in the laser crystal and the crystal is simulated by a thin lens placed at the center of plane-parallel resonator of length (400mm). At what pump power the resonator configuration is equivalent to the concentric resonator. The material parameters required for Nd:YVO_4 are $\frac{dn}{dT}=3\times10^{-6}K^{-1}$, $\alpha=7.07mm^{-1}$, $K_c=0.0054\frac{W}{m.K}$ and assume that (24%) of the pump power results in heating.

(6 Marks)

Q_4: Make the design calculations of a slow axial flow CO_2 laser that has the following output beam and power properties:

Laser power	225W
Beam mode	$TEM_{00}+TEM_{01}$
Beam divergence	2mrad

Include your calculations the following parameters:

a- Determination of laser resonator parameters (resonator type, discharge & resonator length, end mirror curvature & stability check, and laser tube bore diameter).

b- Determination of output coupler transmittance.

c- Selection of mirror materials.

(12 Marks)

Q_5: An Nd:YAG laser is pumped by two linear flashlamps connected in series and pumped a total energy input of (1KJ). Each lamp has an arc length of (10cm) and a bore of (1cm). The power supply is a pulse-forming network with (4) sections with a capacitance of (600μF) per section. If we assume a peak current of (I_p=606A), determine the following parameters:

1. Pulse duration.
2. Pulse rise time.
3. Inductance per section.
4. Capacitor voltage necessary to store explosion energy.

(12 Marks)

Q_6: The slope efficiency σ_s in laser diode determined from the slope of the output power versus input current equal (1W/A) and the bandgap energy of the recombination region equal (1.5eV). calculate the differential quantum efficiency η_d. **(12 Marks)**

Solution of final 2011-2012

Solution (1)

Q1:

The combination of the aperture and the mirror M1 acts on the resonator field as a low pass filter. This accounts for the smoothness of the field profile.

$$R_1 = \frac{2L}{M+1} = 50\ cm \Rightarrow f_1 = 25\ cm$$

100 cm

$$R_2 = \frac{2ML}{M+1} = 200cm \Rightarrow f_2 = 200cm$$

At λ=1.064μm

$$\therefore d = 2(0.61\lambda f_1)^{0.5} \Rightarrow d = 0.08cm$$

$$M_{eff} = 1.5\frac{f_2}{f_1} \Rightarrow M_{eff} = 6$$

$\therefore D = |M_{eff}|d = 0.48cm = 4.8mm$ (beam diameter inside the laser rod)

Q2A:

Lamps usually explode for one of two reasons. The most likely reason is fracture caused by the mechanical shock wave produced by a rapid increase in gas temperature and pressure as the lamp ionizes. Severity of the shock wave is dependent upon rise-time of the current pulse. Thus, discharge circuits are designed to avoid extremely short rise-times.

Even with optimum pulse shape, there is a definite upper limit to the energy a lamp can withstand for any particular pulse duration. If maximum power of the pulse is excessive, pressure inside the lamp exceeds the tensile limit of the envelope, and the lamp explodes.

At values below the explosion energy, but at a significant fraction of the explosion energy, the lamp is still subject to explosion after a number of shots. The shock from the discharge forms microcracks in the envelope, cracks that expand with each pulse. Eventually, the lamp will fail catastrophically with repeated firing.

At energies below the explosion energy, lamp failure consists of a gradual reduction of lamp output for one of two reasons. Optical output may decrease due to contamination of the gas inside the lamp. This can occur because of inadequate cleaning of the lamp components before the lamp is filled or electrochemical processes. For example, impurities trapped in the lamp walls or the electrodes can be liberated by heating and ion bombardment during lamp

operation. A second source of contamination may be leaks in the seals at the ends of the lamp. Air that enters such a leak will contaminate the gas and raise the pressure. If the lamp reaches atmospheric pressure, it cannot be triggered.

Q2B:

Total power absorbed in laser rod = 216W.

Output laser power = 14 watts

H_{LR} = 216 – 14 = 202 watts

Step 3: Convert units of heat power from watts to calories/second.

H_{LR} = 202 watts

$$1 \text{ watt} = \frac{\text{joule}}{\text{sec}}$$

H_{LR} = 202 joules/sec

1 calorie = 4.18 joules

H_{LR} = 202/4.18= 48 cal/sec

Step 4: Determine flow rate. We know that 1 calorie will raise 1 gram of water (or approximately 1 cm^3) 1 degree centigrade. To limit temperature rise in the coolant water to 3 centigrade degrees, dissipating a heat rate of 50 calories/second, the heat exchanger must have a flow rate of 48/4 cm^3 /sec = 12 cm^3 /sec

Step 5: Determine total temperature rise in coolant water. After the water has cooled the laser rod, it must cool the lamp and cavity.

Total heat to be dissipated in coolant (H_{TOT}):

$H_{TOT} = P_{in}$ – power supply losses – laser output

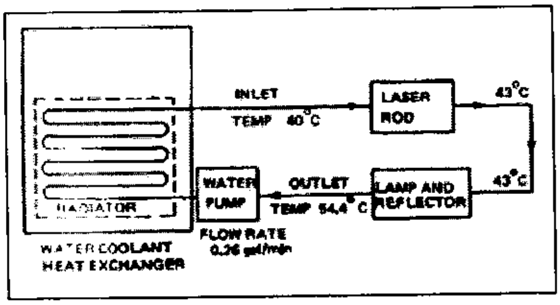
H_{TOT} = 1000 – 200 – 14 = 786 watts

$$H_{TOT} = 786 \ \frac{\text{joules}}{\text{sec}} = 163.41 \text{ cal/sec}$$

Flow rate = 12 cm3 /sec

$$\text{Temperature rise} = \frac{H_{TOT}}{\text{Flow Rate}} = 163.41/12 == 13.6 \ C^{\circ}$$

Temperature rise in coolant = 13.6 centigrade degrees



Q3A:

R_1=infinity

R_2=50cm.

$$L = R_2 - \Delta L = 50cm$$

$$w_2 = \left(\frac{\lambda R_2}{\pi}\right)^{0.2} \left(\frac{L}{R_2 - L}\right)^{0.25}$$

$$w_2 = \left(\frac{\lambda (L + \Delta L)}{\pi}\right)^{0.2} \left(\frac{L}{L + \Delta L - L}\right)^{0.25}$$

$$\sin ce L \succ\succ \Delta L \approx L$$

$$w_2 = \left(\frac{\lambda L}{\pi}\right)^{0.5} \left(\frac{L}{\Delta L}\right)^{0.25} \Rightarrow \Delta L = \left(\frac{\lambda^2 L^3}{\pi^2 w_2^4}\right)$$

$$for w_2 = 1mm \Rightarrow \Delta L = 5.026 \ mm \Rightarrow L = 49.49 \ cm$$

$$for w_2 = 2mm \Rightarrow \Delta L = 0.314 \ mm \Rightarrow L = 49.96 \ cm$$

Q3B:

F=L/4=100mm

$$f = \frac{K\pi w_p^2}{\eta P_{in}\frac{dn}{dT}(1-\exp(-\alpha\ell))} \Rightarrow P_{in} = \frac{K\pi w_p^2}{\frac{dn}{dT}\eta f(1-\exp(-\alpha\ell))} \Rightarrow P_{in} = 37.7W$$

Q5:

$$C_N = \frac{C_T}{N} \Rightarrow C_T = 4\times 600\mu F = 2400\mu F$$

$$R = 1.27\left(\frac{\ell}{d}\right)i^{-0.5} = 1.27\left(\frac{10}{1}\right)(606)^{-0.5} = 0.51\Omega$$

$$Z = 2R = 1.03\Omega \text{ (for two lamps)}$$

$$C_T = \frac{t_p}{2Z} \Rightarrow t_p = 5m\sec \ldots(1)$$

$$N = \frac{t_p}{2t_r} \Rightarrow t_r = 625\mu\sec \ldots(2)$$

$$L_T = \frac{t_p Z}{2} \Rightarrow L_T = 2.575mH$$

$$L_N = \frac{L_T}{N} \Rightarrow L_N = 0.643mH \ldots(3)$$

$$V = \left(\frac{2E}{C_T}\right)^{0.5} \Rightarrow V \approx 913volt$$