THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF PHYSICS

FINAL EXAMINATION

JUNE 2011

PHYS3710/PHYS9710

Lasers and Applications

Time Allowed – 2 Hours

Total number of questions – 5

Answer ALL questions

All questions are of equal value

Candidates should provide their own university-approved calculator

Answers must be written in ink. Except where they are expressly required, pencils may only be used for drawing, sketching or graphical work.

Candidates may keep this paper.

School of Physics

PHYS3710: LASERS AND APPLICATIONS

Speed of light in vacuum c = 3x10^{8} ms^{-1}

Planck's constant h = 6.63x10^{-34} Js

Boltzmann's constant k = 1.38x10^{-23} JK^{-1}

Mass of electron m_0 = 9.11x10^{-31} kg

Charge of electron e = 1.602x10^{-19} C

1eV = 1.602x10^{-19} J

$$E_{ave} = \frac{h\nu}{e^{h\nu/kT} - 1}$$

$$u(\nu) = \frac{8\pi\nu^2}{c^3}\frac{h\nu}{e^{h\nu/kT} - 1}$$

$$R = \frac{A_{ul}}{B_{ul}u(\nu)} = e^{h\nu/kT} - 1$$

$$I(\nu) = I_0 \frac{\Delta\nu/4\pi^2}{(\nu - \nu_0)^2 + (\Delta\nu/4\pi)^2}$$

$$\kappa = \kappa_d \frac{h\nu}{eV}(1 - \frac{I_t}{I})$$

$$I(\nu) = \frac{a}{\Delta\nu^D} exp\left\{-\left[\frac{b(\nu - \theta_0)^2}{(\Delta\nu^D)^2}\right]\right\}$$

$$\sigma(\upsilon) = \frac{\lambda^2}{n^2 8\pi t_{sp}} G_l(\nu)$$

$$N_l/N_u = \exp(E_u - E_l)/kT$$

$$(N_u - N_l) = \frac{(N_u - N_l)_0}{1 + \frac{I}{I_{sat}}}$$

$$E_n = \frac{h^2}{8m^*\pi^2}(\frac{\pi n}{d})^2$$

$$\frac{I_t(\nu)}{I_0} = \frac{1}{1 + (2F/\pi)^2 sin^2(\pi\nu/\Delta\nu)}$$

$$F = \frac{\pi(R_1R_2)^{1/4}}{1 - (R_1R_2)^{1/2}}$$

$$F = \Delta\nu/\delta\nu$$

$$R = [(n_1 - n_2)/(n_1 + n_2)]^2$$

$$I(z) = I(0)e^{gz}$$

$$g_i = 1 + d/\rho_i$$

$$\kappa_d = \kappa_i\kappa_e$$

$$\tau_p = 1/\alpha_{eff}c$$

$$\alpha_{eff} = \alpha_0 + (1/2d)\ln(1/R_1R_2)$$

$$G(\nu_0) = 2/\pi\Delta\nu$$

$$\Delta t_p = 2nd/Nc$$

$$E = E_{bg} + \sum E_n$$

Question 1. (20 Marks)

Discuss briefly the following concepts using words, sketches and/or formulae,

a) Spatial hole burning

b) Distributed Feedback Laser

c) Gain Switching

d) Optical Parametric Amplifier

e) Photon lifetime

Question 2. (20 Marks)

You are given two lasers, A and B, one you would like to operate as a single mode laser and the other you would like to operate as a mode-locked laser. Relevant optical parameters are listed in table 1.

LASER	A	B
Reflectivity of high reflector (%)	100	100
Reflectivity of output coupler (%)	98	95
Spontaneous emission lifetime (μs)	960	3.8
Gain bandwidth (nm)	2	30
Broadening type	inhomogeneous	inhomogeneous
Central wavelength (nm)	1050	1100
Cavity length (cm)	50	120
Refractive index	1.0	1.0

TABLE 1.

a) Explain what mode-locking is and how it is used to achieve light pulses with very high peak intensities.

b) List all of the intra-cavity optical elements that are required to achieve mode-locking and briefly explain their purpose.

c) Calculate the pulse width and pulse separation for each of these lasers.

d) Calculate the reflectivity and spacing for an etalon (refractive index 1.5) that would provide single mode operation for each laser. What is the resulting line-width in each case?

e) Based on your answers to c) and d) which laser would you choose to as the mode locked laser and which the single mode laser? Why?

Question 3. (20 Marks)

Quantum heterostructures based on Group III –V Nitrides, GaN, AlGaN, and InGaN can be used to create laser diodes across the entire visible and UV spectrum. You would like to design a **quantum dot** with square dimensions that emits in the UV at 320nm, using a combination of alloys, where the relevant alloy parameters are given in Table 2.

	Bang Gap energy (eV)	Refractive index	Lattice parameter (nm)	Electron effective mass	Hole effective mass
GaN	3.2	2.5	0.32	0.1	0.4
$Al_{0.6}Ga_{0.4}N$	4.8	2.3	0.31	0.15	0.4
$Al_{0.8}Ga_{0.2}N$	4.9	2.3	0.32	0.1	0.3
$In_{0.8}Ga_{0.2}N$	2.0	2.6	0.33	0.2	0.5

TABLE 2

a) Sketch a simple energy diagram (conduction and valence band) of the heterostructure indicating the materials you have chosen. Provide a reason for your choice.

b) Calculate the energy (in eV) corresponding to the desired emission wavelength.

c) The dimension of the quantum dots used to achieve this emission wavelength.

d) You would like to turn your quantum dot into an electrically pumped diode laser. Describe an efficient electrical pumping scheme for achieving this. What will be the approximate driving voltage for your device?

e) You've achieved light emission from your electrically pumped quantum dot device, but alas, no lasing. What went wrong? What improvements could you make in your next design?

Question 4. (20 Marks)

A typical edge-emitting diode laser has a refractive index of 3.8 and a gain region of dimensions 1 mm long, 200 μm wide and 20 μm in height. The lasing wavelength is 720nm. The laser has intrinsic losses equal to 0.1 cm^{-1} and a confinement factor of 0.8.

a) Sketch a graph of intensity versus current for the diode laser noting all of the important features.

b) What is the effective loss coefficient for this laser?

c) Define the power conversion efficiency of a diode laser.

d) Calculate the power conversion efficiency for this laser given the threshold current density is 100 A/cm^2, internal quantum efficiency is 0.9, and the operating current and voltage is 500mA and 1.7V.

e) Discuss how the power conversion efficiency may be improved.

f) What is the divergence of the beam emitting from the diode laser?

Question 5. (20 Marks)

a) Coherence and ultra-short pulsed operation are two key properties that are distinct to lasers. Briefly explain in terms of the underlying physics how each of these properties comes about and describe how this is used in a specific application.

b) You have been asked by the Australian patent office to evaluate claims by prominent Sydney University researcher, Dr Barry Evil, who has claimed to make the worlds first ultra-low intensity laser. Using your knowledge of what characteristics are common in all lasers explain how you would verify or refute Dr Evil's claim.