THE UNIVERSITY OF NEW SOUTH WALES

SEMESTER 1 2013

PHYS3710: LASERS AND APPLICATIONS

FINAL EXAMINATION

1. TIME ALLOWED – 2 hours

2. READING TIME – 10 minutes

3. THIS EXAMINATION PAPER HAS 5 PAGES

4. TOTAL NUMBER OF QUESTIONS – 5

5. TOTAL MARKS AVAILABLE – 100

6. ALL QUESTIONS ARE OF EQUAL VALUE.

7. ALL ANSWERS MUST BE WRITTEN IN INK. EXCEPT WHERE THEY ARE EXPRESSLY REQUIRED, PENCILS MAY BE USED ONLY FOR DRAWING, SKETCHING OR GRAPHICAL WORK

8. THIS PAPER MAY BE RETAINED BY CANDIDATE

PHYS3710: LASERS AND APPLICATIONS

Speed of light in vacuum c = 3×10^{8} ms^{-1}

Planck's constant h = 6.63×10^{-34} Js

Boltzmann's constant k = 1.38×10^{-23} JK^{-1}

Mass of electron $m_0 = 9.11\times10^{-31}$ kg

Charge of electron e = 1.602×10^{-19} C

1eV = 1.602×10^{-19} J

$$E_{ave} = \frac{h\nu}{\exp[h\nu/kT]-1}$$

$$u(\nu) = \frac{B\pi\nu^2}{c^3}\frac{h\nu}{\exp[h\nu/kT]-1}$$

$$A = 8\pi h\nu^3 B/c^3$$

$$R = \frac{A_{ul}}{B_{ul}u(\nu)} = \exp[h\nu/kT]-1$$

$$g(\nu) = g(\nu_0)\frac{(\delta\nu/2)^2}{(\nu-\nu_0)^2+(\delta\nu/2)^2}$$

$$\alpha_{eff} = \frac{1}{\Gamma}(\alpha_s+\alpha_m)$$

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

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

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

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

$$N_l/N_u = e^{(E_u-E_l)/kT}$$

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

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

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

$$I(\nu) = \frac{1}{\pi}\frac{\Delta\nu/2}{(\nu-\nu_0)^2+(\Delta\nu/2)^2}$$

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

$$R = \left(\frac{n_1-n_2}{n_1+n_2}\right)^2$$

$$Q = \nu_0/\delta\nu$$

$$I(z) = I_0\exp(gz)$$

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

$$\kappa_d = \kappa_i\kappa_e$$

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

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

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

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

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

$$g(\nu) = \alpha(I/I_{tr}-1)$$

$$P = \kappa_d(I-I_t)1.24/\lambda$$

Question 1. (20 Marks)

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

a) Mode locking
b) Gain clamping
c) Resonator stability
d) Rayleigh range
e) Indirect band-gap

Question 2. (20 Marks)

Given that the energy band-gap of GaAs is 1.42 eV and the band-gap of AlGaAs increases above that of GaAs by 13.5 meV for each 1% increase in the Al composition,

a) Calculate the band-gap energy of $Al_{0.3}Ga_{0.7}As$.

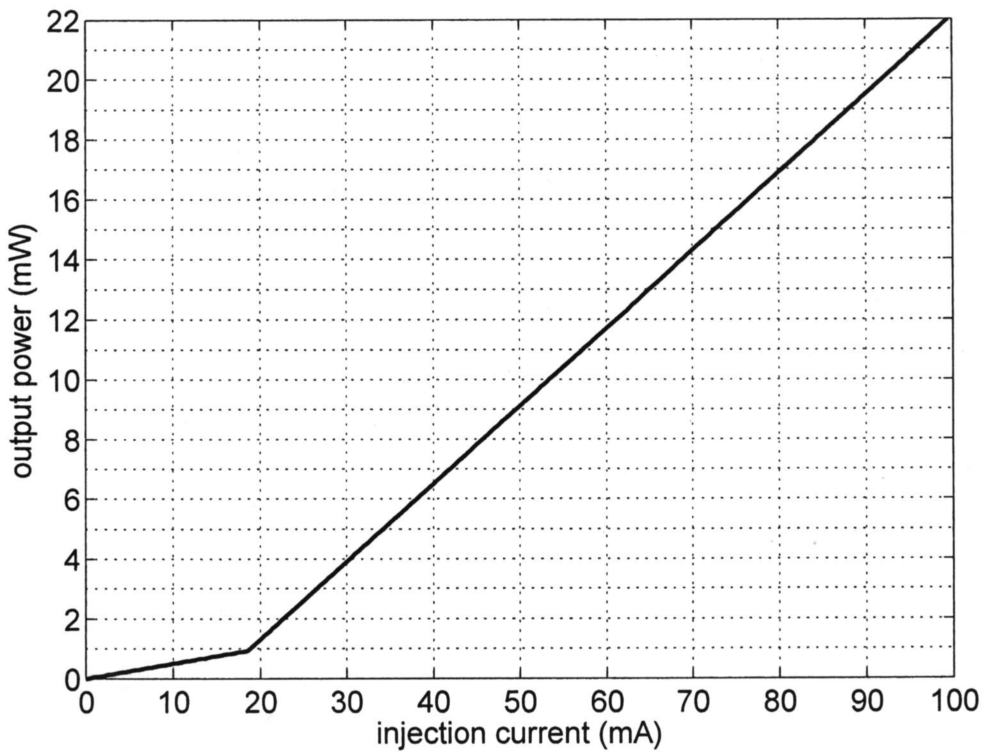
b) Assuming that the conduction band and the valence band offsets are in a ratio of $\Delta E_c : \Delta E_v = 2:1$, draw the energy band diagram of an $Al_{0.3}Ga_{0.7}As/GaAs/Al_{0.3}Ga_{0.7}As$ double heterostructures, marking in the appropriate band-gap energies.

c) If the GaAs layer thickness is only 7 nm, calculate the magnitude of the n=1 electron and hole energy levels relative to the bottom of the respective bands in this $Al_{0.3}Ga_{0.7}As/GaAs/Al_{0.3}Ga_{0.7}As$ quantum well. Assume an infinitely deep well and an effective mass of $0.1m_e$ for electrons and $0.3m_e$ for holes.

d) Using your results from question (c) above, calculate the emission energy of this quantum well.

Question 3. (20 Marks)

Consider an InGaAsP edge-emitting diode laser with uncoated end facets and an emission wavelength of 1550nm. The laser has a length of 200μm, width of 20 μm, thickness of 2 μm, an absorption coefficient = 200 cm^{-1}, refractive index of 3.6, intrinsic optical losses equivalent to 10 cm^{-1}, a radiative recombination time of 10 ns, non-radiative recombination time of 10 ns, and a confinement factor of 0.8. This laser exhibits the following characteristic light-current curve;



(a) Draw a schematic diagram of this laser indicating the pumping scheme, optical resonator and exit aperture.

Calculate:

(b) external differential quantum efficiency for this laser

(c) transparency current density

(d) threshold current **and** slope efficiency if the end facets are covered in highly reflecting coatings with reflectivity R=0.99. Comment on your results.

Question 4. (20 Marks)

Consider a 10 cm long HeNe laser with a Lorentzian lineshape and the following parameters: $\lambda = 632.8$nm, $t_{sp} = 10^{-7}$ sec, n = 1, output power of 1mW and mirror reflectivities $R_1 = 1.0$, $R_2 = 0.98$. Assume that all parasitic losses are negligible when compared to losses through the mirrors. Calculate:

i. Finesse and linewidth

ii. Q factor and the amount of energy stored in the resonator.

iii. Threshold population difference.

To make this laser pulsed you employ a cavity dumping method where the reflectivity of mirror R_1 is instantaneously switched to 0.4. For this new cavity calculate:

iv. Effective loss coefficient

v. Estimated pulse width and peak power per pulse

Question 5. (20 Marks)

a) Explain how the study of nonlinear optics has been enabled by the introduction of the laser. Discuss some examples of how nonlinear optics can be used to generate new high intensity light sources of different wavelengths, including the key considerations for achieving efficient nonlinear frequency conversion.

b) You have been asked by the Australian Patent Office to evaluate claims of the invention of the world's first **zero threshold laser**. Using your knowledge of how lasers work, discuss if such a laser could be made and how you would test the validity of the claims.

"End of Paper"