THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF PHYSICS

FINAL EXAMINATION

JUNE 2012

PHYS3720/PHYS9720

OPTOELECTRONICS

Time Allowed – 2 Hours

Total number of questions – 4

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.

Speed of light in vacuum $c = 3\text{x}10^8$ m/s

Planck's constant $h = 6.63\text{x}10^{-34}$ Js

Boltzmann's const. $k = 1.38\text{x}10^{-23}$ JK^{-1}

Mass of electron $m_0 = 9.11\text{x}10^{-31}$ kg

Charge of electron $e = 1.602\text{x}10^{-19}$ C

$1\text{eV} = 1.602\text{x}10^{-19}$ J

$$NA = \left(n_1^2 - n_2^2\right)^{1/2}$$

$$n(r) = n_1\left[1 - 2\Delta\left(r/a\right)^\gamma\right]^{1/2}$$

$$\Delta\phi = \frac{2\pi}{\lambda}(n\Delta L + L\Delta n)$$

$$\alpha_{\max} = \sin^{-1}\left(NA\right)$$

$$\tan\left(\frac{\phi_s}{2}\right) = \frac{\left[\sin^2\theta - (n_1/n_2)\right]^{1/2}}{\cos\theta}$$

$$\tan\left(\frac{\phi_p}{2} + \frac{\pi}{2}\right) = \left(\frac{n_1}{n_2}\right)^2 \tan\left(\frac{\phi_s}{2}\right)$$

$$M = V^2/2$$

$$P = a/\lambda^4$$

$$P(z) = P(0)e^{-\alpha d}$$

$$\alpha = \frac{2\pi n_1}{\lambda}\left[\left(\frac{n_2}{n_1}\right)^2 \sin^2\left(\theta\right) - 1\right]^{1/2}$$

$$\beta = \left(\frac{10}{L}\right)\log\left(\frac{I_1}{I_2}\right)$$

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

$$R = V/P$$

$$R' = \eta e/h\nu$$

$$R'' = G\eta e/h\nu$$

$$\Delta\tau = \frac{L\lambda}{c}\frac{d^2n}{d\lambda^2}\Delta\lambda$$

$$D^* = \left(A\Delta f\right)^{1/2}$$

$$V = 2\pi bNA/\lambda$$

$$M' = V/\pi$$

$$\Delta\tau = \left(\frac{Ln_1}{8c}\right)\left[\left(n_1 - n_2\right)/n_1\right]^2$$

$$\Delta\tau' = \left(\frac{Ln_1}{cn_2}\right)\left(n_1 - n_2\right)$$

$$\Phi = \eta_e\eta_i\left(i/e\right)$$

$$\Phi = \eta_{ext}h\nu\left(i/e\right)$$

$$B = 1/\left(2\Delta\tau_{12}\right)$$

$$\Delta t = \left(4\omega A\right)/c^2$$

$$k = \left(2\pi n\right)/\lambda$$

$$\Delta\lambda/\lambda = \Delta\nu/\nu$$

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

$$L = 10\log\left(NA_1/NA_2\right)^2$$

$$L = 10\log\left(d_1/d_2\right)^2$$

$$\frac{2\pi}{\lambda}\left(AB + BC\right) - 2\phi = 2\pi m$$

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

$$I = I_0\cos^2\left(\theta\right)$$

$$n(E) = n + a_1E + \frac{1}{2}a_2E^2 + \ldots$$

Question 1

Consider a 2 km long optical fibre with core diameter 12μm. We couple 1450nm wavelength light into the fibre from a laser whose linewidth (full width at half maximum) is 3nm. The refractive index of the core is 1.48 and that of the cladding is 1.47. Calculate the following parameters of this fibre:

a. the numerical aperture
b. the maximum acceptance angle
c. the V-number, and number of modes propagating at this wavelength
d. sketch profile of the 3 lowest order modes
e. the cut-off wavelength for single mode operation
f. the modal dispersion of this fibre
g. approximate the highest bit rate possible using this fibre
h. with the help of Figure 1 below, choose a fibre diameter and operating wavelength which will provide the highest possible bandwidth. Explain your choice

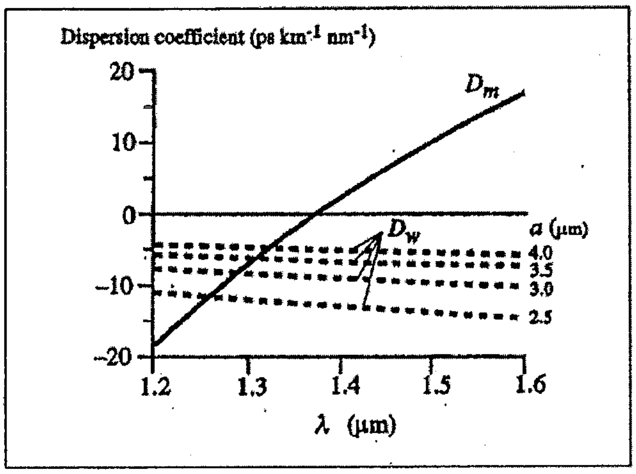

***Figure 1** Material (D_m) and waveguide dispersion (D_w) coefficients for fibre discussed in question 1 above. 'a' represents the radius of the fibres*

Question 2

1. Explain the difference between the internal quantum efficiency (IQE) and power conversion efficiency (PCE) of a light emitting diode and identify which physical effects influence each parameter.

2. Quantum heterostructures based on Group III –V Nitrides, GaN, AlGaN, AlInN and GaInN can be used to create light emitting devices across the entire visible and UV spectrum. You would like to design a **quantum wire** with a square cross-section which emits in the UV at 350nm, using the parameters given in the following table do the following:

    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 corresponding to the desired emission wavelength

    c. The dimension of the quantum wire used to achieve this emission wavelength (assume infinite barrier heights)

    d. Mark on your energy diagram the positions of the energy levels corresponding to first two excited states

    e. Calculate the maximum energy level at which the quantum confinement can still be achieved.

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

Question 3

1. In words and diagrams explain the operation of the following detector types and in each case give one example of a property which superior performance compared to a p-n photodiode:

    a. *pin*-photodiode

    b. avalanche photodiode (APD)

    c. QWIP

2. What noise sources are prevalent for detectors operating in the far infrared spectral region (e.g. in the range of 5-10 μm)

3. A silicon APD has a light receiving area of diameter 1.0mm. When radiation of wavelength 800nm and intensity of 0.1mW/cm^2 is incident this diode generates a photocurrent of 3μA. calculate

    i. Responsivity,

    ii. Quantum efficiency (in %) of the photodiode at 800nm.

    iii. Bandwidth of the detector (defined by the 3dB point), given the following frequency response:

    $$R(v) = \frac{10}{(1 \times 10^{18}) + v^2}$$

    iv. Given that a 200 fA dark current is noise limiting factor calculate the Normalised Detectivity

Question 4

1. Explain the difference between an interferometric and non- interferometric based light modulator, giving examples in each case.

2. Consider a Lithium Niobate Mach-Zhender type Interferometer modulator where phase shifting arm has a 1.4 cm long coplanar strip electrode. If the voltage required to produce a $3\pi/2$ phase shift is 5V, what is the voltage required to reduce the intensity of the light to 20% of the input?

3. Consider the following design of an electro-optic modulator (diagram 1) which is based on the Pockels effect.

    a. Plot a graph of intensity of the transmitted light as a function of applied voltage

    b. Plot a graph of the intensity of the transmitted light with applied voltage when a quarter wave plate is placed at point **A**

    c. Describe how the intensity of the transmitted light with applied voltage will change if the electro-optic element would be replaced with a Kerr type electro-optic material.