IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2015

EEE PART III/IV: MEng, BEng and ACGI

OPTOELECTRONICS

Corrected Copy

Wednesday, 9 December 9:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR questions.

All questions carry equal marks

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible	First Marker(s) :	R.R.A. Syms
	Second Marker(s) :	O. Sydoruk

Fundamental constants

$e = 1.6 \times 10^{-19}$ C

$m_e = 9.1 \times 10^{-31}$ kg

$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

$\mu_0 = 4\pi \times 10^{-7}$ m kg/C^2

$c = 3 \times 10^8$ m/s

$h = 6.62 \times 10^{-34}$ Js

Maxwell's equations – integral form

$\iint_A \underline{\mathbf{D}} \cdot d\underline{a} = \iiint_V \rho \, dv$

$\iint_A \underline{\mathbf{B}} \cdot d\underline{a} = 0$

$\int_L \underline{\mathbf{E}} \cdot d\underline{L} = -\iint_A \partial\underline{\mathbf{B}}/\partial t \cdot d\underline{a}$

$\int_L \underline{\mathbf{H}} \cdot d\underline{L} = \iint_A [\underline{\mathbf{J}} + \partial\underline{\mathbf{D}}/\partial t] \cdot d\underline{a}$

Maxwell's equations – differential form

$\mathrm{div}(\underline{\mathbf{D}}) = \rho$

$\mathrm{div}(\underline{\mathbf{B}}) = 0$

$\mathrm{curl}(\underline{\mathbf{E}}) = -\partial\underline{\mathbf{B}}/\partial t$

$\mathrm{curl}(\underline{\mathbf{H}}) = \underline{\mathbf{J}} + \partial\underline{\mathbf{D}}/\partial t$

Material equations

$\underline{\mathbf{J}} = \sigma \underline{\mathbf{E}}$

$\underline{\mathbf{D}} = \varepsilon \underline{\mathbf{E}}$

$\underline{\mathbf{B}} = \mu \underline{\mathbf{H}}$

Vector calculus (Cartesian co-ordinates)

$\mathrm{grad}(\phi) = \partial\phi/\partial x \, \underline{i} + \partial\phi/\partial y \, \underline{j} + \partial\phi/\partial z \, \underline{k}$

$\mathrm{div}(\underline{\mathbf{F}}) = \partial F_x/\partial x + \partial F_y/\partial y + \partial F_z/\partial z$

$\mathrm{curl}(\underline{\mathbf{F}}) = \underline{i} \{\partial F_z/\partial y - \partial F_y/\partial z\} + \underline{j} \{\partial F_x/\partial z - \partial F_z/\partial x\} + \underline{k} \{\partial F_y/\partial x - \partial F_x/\partial y\}$

$\mathrm{curl}\{\mathrm{curl}(\underline{\mathbf{F}})\} = \mathrm{grad}\{\mathrm{div}(\underline{\mathbf{F}})\} - \nabla^2\underline{\mathbf{F}}$

$\iint_A \underline{\mathbf{F}} \cdot d\underline{a} = \iiint_V \mathrm{div}(\underline{\mathbf{F}}) \, dv$

$\int_L \underline{\mathbf{F}} \cdot d\underline{L} = \iint_A \mathrm{curl}(\underline{\mathbf{F}}) \cdot d\underline{a}$

1. a) Explain what is meant by 'polarization' of light in optics, and give examples of sources emitting light with different degrees of polarization. Explain the meaning of the description 'TE incidence' in an electromagnetic problem.

[5]

b) Starting with the material equations and the differential form of Maxwell's equations, and making assumptions suitable for optical media, derive the time-independent scalar wave equation in the form:

$$\nabla^2 E_y + \omega^2 \mu_0 \varepsilon_0 \varepsilon_r E_y = 0$$

[10]

c) Assuming that E_y is a function only of x and z, propose two different types of wave solution, and show that in each case the solution satisfies the equation above.

[5]

2. a) Figure 2.1 below shows an optical fibre sensor with a phase delay $\phi = \beta \Delta L$ between the sensing and reference arms. What type of interferometer is shown, and what is the type and function of the two components labelled C_1 and C_2?

[4]

b) Describe briefly how the outputs at the points labelled X and Y depend on the parameters of C_1. Assuming unity input power, find the variation in the two detected powers with Φ.

[8]

c) Plot the variation in the two detected powers with Φ, and explain how the device acts a sensor. Discuss the sensitivity and indicate an ideal bias point on your plot.

[8]

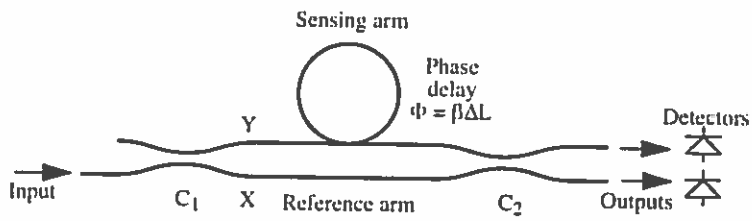

Figure 2.1

3. a) Explain in detail the operation of a channel waveguide Y-junction splitter.

[10]

b) Figure 3.1 shows two single-mode channel guide circuits based on Y-junctions. In each case, the direction and mode amplitude of the input is shown. Explaining your reasoning, calculate the amplitudes at the positions numbered 1) to 6).

[10]

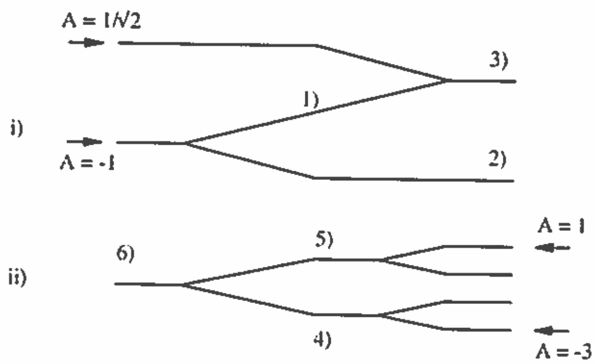

Figure 3.1.

4. a) Sketch the layouts of a star coupler, a non-blocking switch array and a wavelength routing switch.

[6]

b) The coupled mode equations describing the variations of the amplitudes A_1 and A_2 in the two guides of a synchronous directional coupler with distance z are:

$$dA_1/dz + j\kappa A_2 = 0$$
$$dA_2/dz + j\kappa A_1 = 0$$

Here κ is the coupling coefficient. Solve the equations for the boundary conditions $A_1 = 1$, $A_2 = 0$ on $z = 0$, and plot the variation of the powers in the two guides with coupling length. Indicate the coupling length needed for a 3 dB splitter and for a switch. A particular waveguide fabrication process yields a coupling coefficient of $\kappa = 0.5$ mm^{-1}. What coupling length is needed for the couplers in each circuit in part (a)?

[14]

5. a) Table 5.1 summarises the properties of a number of important semiconductor substrate materials. Explaining your reasoning, complete the table. Which material would you use to construct a detector for light of 1.55 μm wavelength?

[7]

b) Explain the difference between radiative and non-radiative recombination. How do these terms appear in the electron rate equation? What is the relation between the radiative and non-radiative electron lifetimes, and what is the quantum efficiency of a light emission process?

[6]

c) Sketch the physical construction and the band diagram of a surface-entry homojunction photodiode. Where is the ideal region for photon absorption, and what is the effect of absorption in other regions?

[7]

Material	E_g (eV) at 300 K	λ_g (μm)	Band structure
Ge	0.66		Indirect gap
InP	1.35	0.92	
GaP	2.2		Indirect gap
Si		1.11	
GaAs	1.42	0.87	Direct gap

Table 5.1

6. a) Explain the difference between a homojunction and a heterojunction. Sketch the band diagram for a PnN double heterojunction, in equilibrium. Why is the double heterostructure so important in optoelectronics?

[10]

b) Derive the phase and gain conditions that must be satisfied at the onset of laser operation. An InGaAsP/InP double heterostructure laser designed for emission at 1.5 μm wavelength has a cavity length of 500 μm and is formed in a material of refractive index 3.5. Estimate the spectral separation of adjacent longitudinal modes, and the gain at the threshold of laser operation.

[10]