National Exams – May 2011
Electro-Optical Engineering

3 hours duration

NOTES:

1. If doubt exists as to the proper interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement about any assumptions made.
2. Candidates may use one of two calculators, the Casio or Sharp approved models.
3. This is a **"Closed-Book"** examination. The candidate may have a single 8.5 inch by 11 inch sheet (both sides) of hand-written notes as an aid for the examination.
4. Any **five** questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.
5. All questions are of equal value.
6. This examination paper has 3 pages.

Values of common constants:

$\varepsilon_o = 8.854 \times 10^{-12}$ F/m
$\mu_o = 4\pi \times 10^{-7}$ H/m
$c = 2.998 \times 10^{8}$ m/s
$q = 1.602 \times 10^{-19}$ C
$h = 6.626 \times 10^{-34}$ J·s
$K = 1.381 \times 10^{-23}$ J/ °K
0°K = -273°C
1 Å = 1.0×10^{-10} m

Si	$\varepsilon_r = 11.8$
Si	$n = 3.42$
Si	$E_g = 1.11$ eV
Ge	$\varepsilon_r = 16.0$
Ge	$n = 4.01$
Ge	$E_g = 0.67$ eV
GaAs	$\varepsilon_r = 13.2$
GaAs	$n = 3.63$
GaAs	$E_g = 1.41$ eV
InGaAsP	$n = 3.5$
$LiNbO_3$	$\varepsilon_r = 32$
$LiNbO_3$	$n_o = 2.30$

Useful formulas:

$$\int \frac{dx}{a^2 + x^2} = \frac{1}{a}\arctan\left(\frac{x}{a}\right) \qquad P(n) = \frac{N^n \exp(-N)}{n!}$$

$$Al_xGa_{1-x}As \quad E_g(eV) = 1.424 + 1.266x + 0.266x^2$$

$$I_s = R_o\sqrt{P_o P_1}\cos\theta \qquad n(E) = n_0 - \frac{1}{2} r n_0^3 E \qquad x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Question 1

(a) Sketch the loss versus wavelength curve for a silica fiber and label all the important features.

(b) What is Rayleigh scattering and how would it appear on an optical time domain reflectometer test of an optical fiber?

(c) Each of the following fibers has n_{core}=1.454 and n_{clad}=1.450. Each also has chromatic dispersion 10ps/(nm-km). Determine the numerical aperture, number of modes and approximate band-width length (BL) product for each fiber if the source is a laser diode at 1550 nm with rms spectral width 2 nm and RZ signalling is used for the digital signal.

  (i) silica fiber with 25 μm core radius.

  (ii) silica fiber with 5 μm core radius.

(d) What is a DWDM optical link? You must choose a single mode fiber for a DWDM optical link. You can choose one with 20, 2, 0 or –5 ps/(nm-km) chromatic dispersion. Which fiber would you choose and explain your choice.

Question 2

(a) An optical fiber has core diameter 62 μm and NA=0.28 . The output light from the fiber is collimated by a lens with focal length 10 mm. What is the diameter of the collimated beam and what is the beam divergence?

(b) Two compatible multimode stepped-index fibers are joined in a mechanical splice with a small air gap. The fiber axes and end faces are perfectly aligned in the splice. Determine the index of refraction of the fiber core if the splice has loss 0.35 dB.

(c) A Mach-Zehnder interferometer (MZI) can be used as an optical intensity modulator. Consider a MZI made on $LiNbO_3$ crystal substrate having electro-optic coefficient r = 30pm/V. The thickness of the substrate is 1 mm. The MZI uses channel optical waveguide with very good optical confinement. One arm of the MZI has a set of electrodes of length 1 cm across which a voltage is applied. The electrode spacing is 25 μm. A single mode silica fiber (n_{core}=1.5) is attached to each end of the MZI.

  (i) Sketch the device and describe how it acts as a light intensity modulator.

  (ii) What is the voltage required for zero light output?

  (iii) If a laser diode at 1550 nm is used as the light source and the diode has spectral width 100MHz, check that the coherence length of the fiber/device is adequate to ensure proper operation of the MZI.

  (iv) What is the advantage of such an external modulator over direct modulation?

Question 3

(a) A laser diode must operate close to 1550 nm wavelength. The length of its cavity is 300 μm and the effective width of the gain curve is 9 nm. The active layer has refractive index 3.55 and the effective confinement factor is 1.0

  (i) What is the lasing wavelength closest to 1550 nm?

  (ii) How many lasing modes does the diode have? Sketch the spectrum of the laser diode.

  (iii) What is the finesse of the laser diode cavity?

  (iv) If the extra cavity losses not accounted for in the cavity reflectance loss are 3 dB/cm, what is the threshold gain of the laser diode?

  (v) What is the photon lifetime in the laser diode?

  (vi) What is the slope efficiency in W/A of the laser diode above the threshold current.

(b) The effective width of the active layer in a laser diode can be defined by index-guiding or by gain-guiding. Explain the difference between these two methods. Use diagrams to illustrate your answer.

(c) Direct modulation of a laser diode is limited to a modulation rate of a few GHz . What limits the modulation rate, and how would you operate the diode to achieve the maximum direct modulation rate? Explain your answers.

Question 4

(a) Discuss unique properties of a P-n-N double heterostructure LED and sketch with proper labelling the energy-band diagram of the structure.

(b) An $Al_xGa_{1-x}As$ LED is designed for peak emission wavelength of 820 nm at 25°C. What is the mole fraction x?

(c) What is the expected FWHM spectral width of the LED in part (b)?

(d) A GaAs LED is forward biased with current 100 mA at a voltage of 1.5V, and each emitted photon has energy 1.43 eV. For the GaAs material, n = 3.63, the minority carrier lifetime for radiative and non-radiative recombination is 120 ns and 100 ns, respectively, and the absorption loss is 10%. Calculate

(i) the internal quantum efficiency of the LED

(ii) the internal power efficiency of the LED

(iii) the external power efficiency if the LED is emitting into air.

Question 5

A 1550 nm single mode digital fiber optic link needs to operate at 565 Mb/s in NRZ format over 50 km without repeaters. A single mode InGaAsP laser diode launches an average optical power -13 dBm into the fiber. The laser diode has RIN noise –120dB/Hz. The laser diode has 1 nm spectral width and the rise time of the transmitter is 0.5 ns. The fiber has a loss of 0.35 dB/km and dispersion 2.5 ps/(nm-km). There is a splice with loss of 0.1 dB every kilometer. The coupling loss at the receiver is 0.5 dB and the receiver uses an InGaAs APD with sensitivity of -39dBm. The receiver bandwidth is 500 MHz. Excess noise penalties are predicted to be 1.5 dB.

(a) Set up an optical power budget for this link and find the system margin.

(b) Calculate the system risetime. What can you conclude about the design of the system?

(c) If the data was in RZ format instead of NRZ format, what would be the effect on the system design?

Question 6

(a) A photodetector can be operated in the photovoltaic mode or the photoconductive mode. Draw the IV diagram of a photodetector under different levels of optical illumination, and show the load lines for photoconductive and photovoltaic operation. Discuss the advantages and disadvantages of each mode of operation.

(b) If the received power at a photodetector is 1 nW at a wavelength of 0.85μm, what is the probability that fewer than 3 photons will be received in an interval of 1 ns?

(c) An optical link consists of a laser diode emitting light at 1.3 μm, a fiber cable with 10 dB of loss, and a PIN photodetector with responsivity 0.5A/W. The detector's dark current is 2nA. The load resistance is 100Ω. The total capacitance of the receiver circuit is 15pF and the receiver operates at 27°C. The system losses in addition to fiber attenuation include a 13dB power reduction owing to source coupling, and a 4 dB loss caused by various splices and connectors. The laser diode emits constant 2 mW of power and has RIN noise of –100dB/Hz. Calculate the signal-to-noise ratio at the receiver in dB.

(d) What is a transimpedance amplifier and what are the advantages of an optical receiver using it?

Marking Scheme

Question 1
Marking: 20 marks distributed as
(a) 4 marks
(b) 2 marks
(c) 11 marks
(d) 3 marks

Question 2
Marking: 20 marks distributed as
(a) 5 marks
(b) 5 marks
(c) 10 marks

Question 3
Marking: 20 marks distributed as
(a) 12 marks
(b) 4 marks
(c) 4 marks

Question 4
Marking: 20 marks distributed as
(a) 4 marks
(b) 5 marks
(c) 3 marks
(d) 8 marks

Question 5
Marking: 20 marks distributed as
(a) 10 marks
(b) 7 marks
(c) 3 marks

Question 6
Marking: 20 marks distributed as
(a) 6 marks
(b) 4 marks
(c) 8 marks
(d) 2 marks