National Exams – December 2018
17-Phys-B2, 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 - full marking scheme can be found on page 4.
6. This examination paper has 4 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 x10^{-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	$n = 3.4$
$LiNbO_3$	$\varepsilon_r = 32$
$LiNbO_3$	r = 30pm/V
$LiNbO_3$	$n_o = 2.30$

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

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

$I_s = R_o\sqrt{P_oP_1}\cos\theta \qquad n(E) = n_0 - \frac{1}{2} r n_0^{\,3} E \qquad x_{1,2} = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$

Question 1

Consider a silica step index fiber having core diameter 62.5μm, core index 1.46 and cladding index 1.459. It has chromatic dispersion of 15ps/(nm-km) at 1550nm. The source emits at 1550nm and has a linewidth of 120nm.

(a) What is the acceptance angle of the fiber?
(b) Approximately how many modes can propagate?
(c) What is the modal dispersion?
(d) What is the chromatic dispersion?
(e) What is the bandwidth-length product for RZ digital signaling?
(f) At what bend radius does a ray travelling along the fiber axis strike the cladding at the critical angle in the bend for a given mode?
(g) What is polarization dispersion in a fiber and how does it arise?

Question 2

(a) A GaAs laser diode has a 1.5nm gain bandwidth and a cavity length of 0.5mm. Sketch the output spectrum including as many quantitative details as you can.
(b) Explain what is meant by laser relative intensity noise and describe its origins. What is its effect on optical communication system design?
(c) What is a DFB laser diode? Sketch its basic features and explain its operation. What are its benefits?
(d) Compute the grating period for an InGaAsP DFB laser diode operating at 1550nm.

Question 3

A PIN detector diode has responsivity 0.25A/W, and dark current 0.5nA. It has a depletion layer width 30μm, a carrier velocity of 5×10^4m/s and junction capacitance 0.45pF. It operates at 27^0C. It is reverse-biased at 10V and the load resistor is 2MΩ.

(a) Draw the detector circuit and write the loop equation.
(b) Draw the load line on an I-V graph.
(c) At what value of the optical power does the detector saturate?
(d) Determine and sketch the output voltage versus input optical power from optical power levels 5μW to 50μW
(e) Sketch approximately the diode I-V characteristic under illumination on the same graph as your load line in part (b). In which mode is the diode operating?
(f) Is the bandwidth transit-time limited or RC limited?

Question 4

The optic power reaching a receiver is 1μW at 1.3μm wavelength. The detector's sensitivity is 0.5A/W and its dark current is 4nA. The temperature is 27^0C. The receiver's bandwidth is 500MHz and the load resistance is 50Ω.

(a) What is the signal-to noise ratio (SNR)?
(b) What is the thermal noise-limited SNR?
(c) What is the shot-noise limited SNR?
(d) What value of photodetector gain is required to make the actual SNR just 5dB less than the quantum limit? Assume that the photodetector has negligible excess noise.
(e) If the system operates as 100Mbps PCM, how many incident photons arrive per bit?

Question 5

A Y-branch Mach Zehnder interferometer is a very useful optical component.

(a) Draw its basic structure and describe its operation.

(b) Assuming ideal operation, derive and sketch its input/output transfer function for optical intensity.

(c) Describe how it can be used as an optical amplitude modulator.

(d) Describe how it can be used as an optical switch.

(e) Describe how two of them can be combined to make a 4-QAM modulator.

(f) What factors limit the speed of the modulation or switch?

Question 6

(a) There are two basic types of LEDs. Name and sketch the basic physical structure of these two types. Also describe the advantages and disadvantages of each of them.

(b) What is the relationship between LED bandwidth and carrier recombination? What is the bandwidth of an LED source with a risetime of 12ns?

(c) A GaAs LED operates at 27^0 C, with a bias current of 15 mA and it has quantum efficiency of 18%. Calculate the wavelength, the approximate spectral width, and the intensity of the light wave from this LED.

(d) An LED delivers power of 100 μW at a wavelength of 0.85 μm into an optical fiber. The total attenuation between transmitter and receiver is 40 dB. What is the probability that fewer than 3 photons will be received in an interval of 1 ns?

Question 7

An optical communications link is designed to transmit data over an optical fiber with core diameter 10μm, core index 1.465 and cladding index 1.461, loss 0.2 dB/km, and dispersion Coefficient D=20ps/(nm-km). The link has a total length of 100km, six splices with loss 0.05 dB per splice loss, and two connectors with 0.2dB loss per connector. The laser diode of the transmitter operates at 2.5 Gb/sec at a central wavelength of 1550 nm, with a spectral linewidth of 0.5nm. The receiver sensitivity is 20μW.

(a) Is the fiber operating single mode?
(b) Show that the link cannot operate at the intended data rate.
(c) To achieve the specified data rate, a length of dispersion compensating fiber (DCF) having dispersion parameter D= -100 ps/(nm-km) is inserted at the end of the link. What is the minimum length of DCF that is needed?
(d) If the DCF that must be inserted has one splice and one connector and loss 0.5 dB/km, what is the minimum transmitter power expressed in both dBm and W.
(e) Describe how the dispersion coefficient of a fiber can be designed for a specific value.

Marking Scheme - a full paper constitutes any 5 questions

Question 1 = 20 marks
- (a) 2 marks
- (b) 2 marks
- (c) 3 marks
- (d) 3 marks
- (e) 3 marks
- (f) 4 marks
- (g) 3 marks

Question 2 = 20 marks
- (a) 6 marks
- (b) 6 marks
- (c) 6 marks
- (d) 2 marks

Question 3 = 20 marks
- (a) 4 marks
- (b) 4 marks
- (c) 2 marks
- (d) 4 marks
- (e) 3 marks
- (f) 3 marks

Question 4 = 20 marks
- (a) 6 marks
- (b) 3 marks
- (c) 3 marks
- (d) 5 marks
- (e) 3 marks

Question 5 = 20 marks
- (a) 4 marks
- (b) 5 marks
- (c) 3 marks
- (d) 2 marks
- (e) 4 marks
- (f) 2 marks

Question 6 = 20 marks
- (a) 6 marks
- (b) 2 marks
- (c) 6 marks
- (d) 6 marks

Question 7 = 20 marks
- (a) 3 marks
- (b) 5 marks
- (c) 3 marks
- (d) 5 marks
- (e) 4 marks