National Exams – December 2012
07-Elec-B10, 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	$n = 3.5$
$LiNbO_3$	$\varepsilon_r = 32$
$LiNbO_3$	$r_{63} = 30$pm/V
$LiNbO_3$	$n_o = 2.30$

Useful formulas:

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

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

$$I_s = R_o\sqrt{P_o P_1}\cos\theta \qquad n(E) = n_0 - \frac{1}{2} r_{63} n_0^{\,3} E \qquad x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Question 1

A step-index optical fiber has core diameter 62.5 μm, core refractive index 1.455, and a cladding refractive index of 1.445 . The fiber is operated at λ=870 nm.

(a) Calculate the V-number for the fiber and estimate the number of modes.
(b) Calculate the wavelength beyond which the fiber becomes single mode.
(c) Calculate the numerical aperture of the fiber and the maximum acceptance angle.
(d) For NRZ signaling, calculate the modal dispersion $\Delta\tau$ and hence the BL product given that the rms dispersion is σ=0.29 $\Delta\tau$ in which $\Delta\tau$ is measured at FWHM.
(e) Explain the advantages that a multimode GRIN fiber has compared with a step-index fiber.

Question 2

A silicon PIN photodiode has a quantum efficiency of 70% at a wavelength of 0.85μm. It has a capacitance of 6 pF, and a dark current of 10 nA

(a) Calculate the mean photocurrent when the detector is illuminated at a wavelength of 0.85μm with 10μW of optical power.
(b) Calculate the rms quantum noise current in a post detection bandwidth of 30MHz.
(c) Determine the minimum load resistance corresponding to a post detection bandwidth of 30MHz.
(d) Calculate the rms thermal noise current in the resistor from (c) at a temperature of 25°C.
(e) Calculate the rms noise current due to dark current.
(f) Calculate the SNR in dB for the signal in (a), and all noise sources.

Question 3

A PCM-ASK system having a data transmission rate 350 Mb/s at a wavelength 1310 nm must have a signal-to noise ratio of 27 dB in the detected signal for a BER=10^{-9}. The quantum efficiency of the PIN photodiode is 0.65 . Neglect amplifier noise. The operating temperature is 27°C. Assume the signal threshold is set half-way between the two signal levels for a detected "1" and "0". Calculate the sensitivity of the system for the following different detection schemes.

(a) Direct detection, including thermal noise from a load resistor of 1200 Ω.
(b) A homodyne detector, with local oscillator power of 0 dBm and phase error of 18 degrees.

Question 4

(a) A structure suitable for making lasers with an operating wavelength of 1550 nm has a 0.1 μm thick InGaAsP active layer. In this structure 5μm wide and 300 μm long index-guided lasers are fabricated. Experimentally the threshold current is found to be 1kA/cm^2 and the losses in the cavity are found to be 10dB/cm.
   (i) Calculate the gain of the active layer at threshold.
   (ii) Calculate the maximum power per facet at 3kA/cm^2 if the contribution from spontaneous emission can be neglected and the internal efficiency is 70%.
(b) Explain the structure and operation of a DFB laser. What is the critical relationship which must be satisfied in the Bragg grating?
(c) What is relative intensity noise of a laser diode and what is its origin? What effect can relative intensity noise have on laser diode operation and how can this be avoided?

Question 5

A longitudinal electro-optic Pockel cell modulator of *$LiNbO_3$* is designed for amplitude modulation of light having wavelength 850nm. It consists of an input polarizer, λ/4 plate, the crystal itself and an output crossed polarizer. The modulating voltage is applied through transparent electrodes on the input and output faces of the crystal. The crystal has cylindrical geometry with a diameter of 20 mm and a length of 4 mm. The *RC* limited bandwidth of the modulator is 150 MHz, where *R* is the source resistance and *C* is the (parallel plate) capacitance of the crystal.

(a) Make a sketch of this Pockel-cell modulator and explain how the modulation is achieved.
(b) Calculate the voltage needed for maximum light transmission.
(c) Sketch the transfer function of the modulator (output intensity vs. input voltage) and write an expression for the transfer function.
(d) What power does a sinusoidal signal generator need to operate the modulator at 10% modulation index?
(e) If the absorption of the crystal at 850 nm is 3%, and the external components add 2% absorption, what is the total transmission loss through the modulator?

Question 6

A 50 km fiber link uses a fiber with loss .04 Np/km, core diameter 8 μm, core index 1.451, numerical aperture 0.12, and chromatic dispersion 17 ps/nm/km. The source is a 1550 nm laser diode emitting 1 mW. The laser diode has spectral width 3 nm at FWHM. The receiver photodiode has sensitivity -35dBm and responsivity 0.9A/W.

(a) Verify that this fiber will operate single mode for the specified wavelength and calculate the index of the cladding assuming stepped-index fiber.
(b) Taking into account the Fresnel reflection loss at each end of the fiber, total fiber splice loss of 6dB, the attenuation of the fiber itself, and 1 dB loss in coupling the laser diode to its pigtail fiber, calculate the total link loss, the system margin, and the output power that reaches the receiver. Express total loss and system margin in dB. Express output power in μW, and dBm. Also calculate the photodetector signal current.
(c) Estimate the maximum bit rate that can be transmitted for an RZ digital signal.
(d) Discuss the various contributions to attenuation of typical silica core fiber at 1550nm.
(e) What is the fiber mode that is propagating? Sketch its intensity distribution and polarization in the fiber core.

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Question 1

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

Question 2

Marking: 20 marks distributed as
(a) 3 marks
(b) 3 marks
(c) 3 marks
(d) 3 marks
(e) 3 marks.
(f) 5 marks

Question 3

Marking: 20 marks distributed as
(a) 10 marks
(b) 10 marks

Question 4

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

Question 5

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

Question 6

Marking: 20 marks distributed as
(a) 4 marks
(b) 6 marks
(c) 4 marks
(d) 3 marks
(e) 3 marks