The University Of Sheffield.

Data Provided: None

Speed of light, $c = 3.00 \times 10^{8}\ ms^{-1}$

The Boltzmann constant, $k_B = 1.38 \times 10^{-23}\ JK^{-1}$

The Planck constant, $h = 6.63 \times 10^{-34}\ Js$

Electron charge, $e = 1.60 \times 10^{-19}\ C$

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2013-14 (2.0 hours)

EEE6041 Optical Communication Devices and Systems

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. **a.** (**i**) Describe the structure of an optical waveguide.

(**ii**) State and explain the formation mechanism of optical modes in a waveguide based on a ray optics model with the aid of suitable diagrams.

(**iii**) Explain how a single mode or multiple modes are formed in a waveguide using a planar waveguide as an example. **(9)**

b. Define the following concepts which are related to optical fibres:

(**i**) Total internal reflection

(**ii**) Numerical aperture

(**iii**) Acceptance angle **(6)**

c. Determine the maximum core thickness for a planar waveguide in order to obtain single-mode operation at 1.55 µm, assuming the waveguide with a relative refractive index difference of 1% and the core refractive index of 1.50. **(5)**

2. **a.** (**i**) Compare the formation mechanisms of intrinsic absorption and extrinsic absorption in a silica fibre.

(**ii**) Describe the formation mechanisms of intermodal dispersion and intramodal dispersion in silica fibres, and briefly explain the reasons for optical pulse broadening due to different optical dispersion mechanisms. **(6)**

b. (**i**) State the formation mechanisms of regeneration errors in a receiver of digital system.

(**ii**) Describe the "eye diagram" used in digital signal transmissions, and explain how to use the "eye diagram" to evaluate the quality of the digital signals. **(6)**

c. Consider a single-mode fibre link operating at 1.55 µm with a fibre loss of $\alpha = 0.4$ dB/km. A data rate of 2.5 Gbit/s is requested. The input optical power is 1 mW, and the receiver requires that the minimum number of photons per bit (N_p) is

1000. Ten optical connectors each with an optical loss of 0.3 dB and two optical splices each with a 0.1 dB loss are used. Furthermore, an EDFA with a gain of 20 dB is used as an optical amplifier. A power margin of 10 dB is required.

(i) Calculate the maximum optical loss allowed for the optical fibre used.

(ii) Briefly describe and explain the operational mechanism of EDFA.

(iii) Calculate the maximum transmission distance with regard to loss in the system. **(8)**

3. **a.** Compare the following photo-detectors in terms of operational mechanisms, photocurrent gain and bandwidth.

(i) PIN photodiode

(ii) Avalanche photodiode **(6)**

b. Considering InGaAs (dielectric constant ε= 12) based PIN photodiode used with a preamplifier with a 50Ω impedance, assuming (1) 10 µm thick i-region; (2) optical window in a 200 µm diameter; and (3) saturation velocity = 10^5 m/s

(i) Describe and explain the factors which determine the maximum bandwidth of the PIN photodiode, and compare the response time due to the different factors.

(ii) Determine the maximum bandwidth of the photodiode.

(iii) In general term, explain how you can modify a PIN photodiode in order to increase the maximum bandwidth. **(7)**

c. Calculate the multiplication factor of an InGaAsP/InP avalanche photodiode with a quantum efficiency of 85% at 1.55 µm, assuming an incident optical power of 1.0 µW and the output current of 20 µA. **(3)**

d. Describe a cut-off wavelength of a photo-detector. Determine the room-temperature cut-off wavelength of an intrinsic photo-detector fabricated from silicon, assuming its bandgap energy of 1.11 eV at room temperature. Briefly explain why a photodetector is generally operated at a low temperature. **(4)**

4 **a.** Define the following phenomena when the drive current for a laser is modulated at high frequency for optical communications.

(i) Relaxation oscillations

(ii) Frequency chirp **(6)**

b. (i) Compare the operational mechanisms of light emitting diodes (LEDs) and laser diodes (LDs) in terms of light emission and absorption processes, and explain the advantages of using laser diodes for optical communications compared with LEDs.

(ii) Briefly describe wavelength division multiplexing (WDM) in fibre optical communications, and explain the necessity of using LDs for a dense WDM system. **(8)**

c. Provide a few examples of low dimensional laser diodes; briefly describe and explain their advantages compared with conventional laser diodes. **(6)**