



Course Name: Optoelectronics
Course Code: ECE491
Spring Semester Final term Exam.
BME Program
Level 300
Exam Date: 21-5-2018
Allowed Time: 120 Minute



Attempt all questions. Assume any missed data. Full mark is 50.

Question One (25 mark)

Q.1.a) Mention in brief, what are the meant by: i. Direct and indirect bandgap recombination process. ii. LASER and Avalanche photodiode iii. light amplification conditions [4 Marks]

Q.1.b) An APD has a quantum efficiency of 45% at $0.85 \mu\text{m}$. When illuminated with radiation of this wavelength it produces an output photocurrent of $10 \mu\text{A}$ after avalanche gain with a multiplication factor of 250. Calculate the received optical power to the device. How many photons per second does this correspond to? [4 Marks]

Q.1.c) The coated mirror reflectivity at either end of the $350 \mu\text{m}$ long optical cavity of an injection laser is 0.5 and 0.65. At normal operating temperature the threshold current density for the device is $2 \times 10^3 \text{ A cm}^{-2}$ and the gain factor β is $22 \times 10^{-3} \text{ cm A}^{-1}$. Estimate the loss coefficient in the optical cavity. [4 Marks]

Q.1.d) A ruby laser contains a crystal of length 0.04 m with a refractive index of 1.78. The peak emission wavelength from the device is $0.55 \mu\text{m}$. Determine the number of longitudinal modes and the absolute temperature in kelvin if the Einstein's ratio between the stimulated and spontaneous emission rates is 2. [5 Marks]

Q.1.e) Sketch and discuss the basic principle of Fabry Perot resonator with clearing cavity length oscillation condition and active medium gain threshold? [4 Marks]

Q.1.f) A 66 km single mode optical fiber has a core diameter is $6 \mu\text{m}$ and operating at a wavelength of 1300 nm . If a laser source with bandwidth 800 MHz and power 2 W launched into a fiber. compare the threshold optical powers for stimulated Brillouin and Raman scattering within the fiber at the wavelength specified if the measured mean power at the fiber end is 1 mw . [4 Marks]

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Question Two (25 mark)

Q.2.a) Design a Fabry-Perot cavity for a ruby laser contains a crystal of length L cm with a refractive index of n . The peak emission frequency from the device is 428 THz and the number of longitudinal modes is 3×10^5 . Determine n , L if the separation wavelength is 2 nm. [4 Marks]

Q.2.b) Briefly explain the reasons for pulse broadening due to material dispersion in optical fibers and derive its mathematical formulas? [4 Marks]

Q.2.c) A multimode step index fiber has a numerical aperture of 0.3 and a core refractive index of 1.45. The material dispersion parameter for the fiber is $250 \text{ ps nm}^{-1} \text{ km}^{-1}$ which makes material dispersion the totally dominating chromatic dispersion mechanism. Estimate (a) the total rms pulse broadening per kilometer when the fiber is used with an LED source of rms spectral width 50 nm and (b) the corresponding bandwidth-length product for the fiber. [4 Marks]

Q.2.d) How to reduce various types of dispersion in optical fibers? [4 Marks]

Q.2.e) Calculate the transmission bit rate for return to zero data format of optical fibers communication system according to International Telecommunications Union (ITU) spectral band designations? [4 Marks]

Q.2.f) Design and explain an optical counter to measure a heart beat rate? [5 Marks]

Hints: solve using the following formulas

The Rayleigh scattering coefficient: $\gamma_R = \frac{8\pi^3}{3\lambda^4} n^8 p^2 \beta_c K T_F$	$P_B = 4.4 \times 10^{-3} d^2 \lambda^2 \alpha_{dB} v$, watts
Relative refractive index difference $\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$	$P_R = 5.9 \times 10^{-2} d^2 \lambda \alpha_{dB}$, watts
Fresnel reflection coefficient is $r = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2$	The threshold current density $J_{th} = \frac{g_{th}}{\beta} = \frac{I_{th}}{\text{area of the optical cavity}}$

My best wishes to all of you!

Dr. Bedir Yousif



Question One (25 mark)

Q.1.a) Mention in brief, what are the meant by: i. Direct and indirect bandgap recombination process. ii. LASER and Avalanche photodiode iii. light amplification conditions [4 Marks]

i- Energy-momentum diagrams showing the types of transition: Fig 1. (a) direct bandgap semiconductor; Fig 1. (b) indirect bandgap semiconductor

direct bandgap	indirect bandgap semiconductor
electron-hole recombination have the same momentum	electron-hole recombination have different momentum
Recombination process is fast	recombination process is relatively slow.
GaAs, InAs	Si, Ge
Recombination coefficient is very big value	Recombination coefficient is a small value

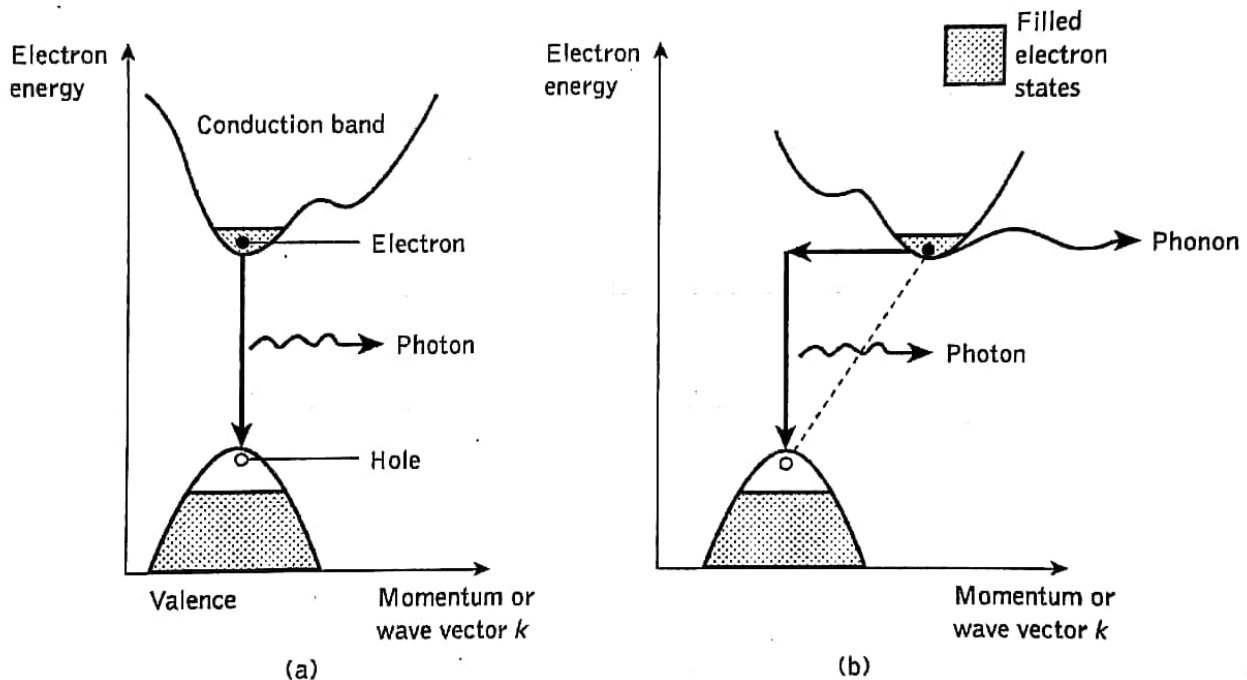


Fig 1. (a) direct bandgap semiconductor; Fig 1. (b) indirect bandgap semiconductor

ii- LASER and Avalanche photodiode

LASER (F.B)	APD (R.B)
Convert electric current into light	Convert light into electric current
Used for long distance transmission	Used for high responsivity
Light source	Light detector
Light amplification	Current amplification

iii- light amplification conditions

a- Achieving population inversion
satisfied

b- Active medium gain threshold must be

Q.1.b) An APD has a quantum efficiency of 45% at 0.85 μm . When illuminated with radiation of this wavelength it produces an output photocurrent of 10 μA after avalanche gain with a multiplication factor of 250. Calculate the received optical power to the device. How many photons per second does this correspond to? [4 Marks]

$$\eta = \frac{r_e}{r_p}, R = \frac{I_p}{P_o}, r_p = \frac{P_o}{hf}$$

$$R = \frac{\eta e \lambda}{hc} = \frac{0.45 \times 1.6 \times 10^{-19} \times 0.85 \times 10^{-6}}{6.626 \times 10^{-34} \times 3 \times 10^8} = 0.308 \text{ Aw}^{-1}$$

$$I_p = \frac{I}{M} = \frac{10 \mu\text{A}}{250} = 0.04 \mu\text{A}$$

$$P_o = \frac{I_p}{R} = \frac{0.04 \mu\text{A}}{0.308 \text{ Aw}^{-1}} = 129.8 \text{ nW}$$

$$r_p = \frac{P_o}{hf} = \frac{129.8 \text{ nW} \times 0.85 \times 10^{-6}}{6.626 \times 10^{-34} \times 3 \times 10^8} = 5.55 \times 10^{11} \text{ photons/second}$$

Q.1.c) The coated mirror reflectivity at either end of the 350 μm long optical cavity of an injection laser is 0.5 and 0.65. At normal operating temperature the threshold current density for the device is $2 \times 10^3 \text{ A cm}^{-2}$ and the gain factor β is $22 \times 10^{-3} \text{ cm A}^{-1}$. Estimate the loss coefficient in the optical cavity. [4 Marks]

The threshold current density may be obtained from Eq. (4.24) where:

$$J_{th} = \frac{1}{\beta} \left[\bar{\alpha} + \frac{1}{2L} \ln \frac{1}{r_1 r_2} \right] = \frac{1}{22 \times 10^{-3}} \left[\alpha + \frac{1}{2 \times 350 \times 10^{-4}} \ln \frac{1}{0.325} \right] = 2 \times 10^3$$

$$\alpha = 28 \text{ cm}^{-1}$$

Q.1.d) A ruby laser contains a crystal of length 0.04 m with a refractive index of 1.78. The peak emission wavelength from the device is 0.55 μm . Determine the number of longitudinal modes and the absolute temperature in kelvin if the Einstein's ratio between the stimulated and spontaneous emission rates is 2. [5 Marks]

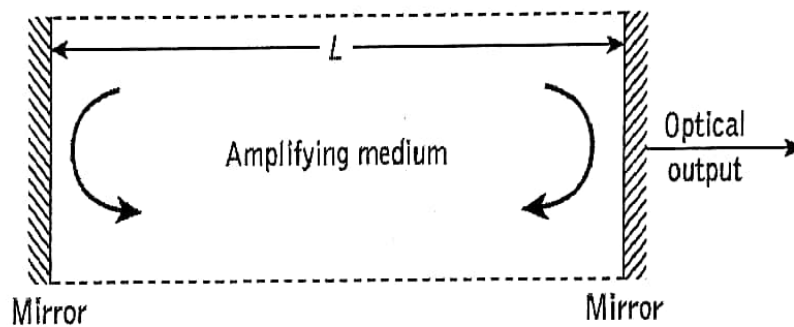
The number of longitudinal modes supported within the structure may be obtained from

$$q = \frac{2nL}{\lambda} = \frac{2 \times 1.78 \times 0.04}{0.55 \times 10^{-6}} = 2.6 \times 10^5$$

$$\frac{hf}{KT} = \ln(1.5) = 0.405$$

$$T = \frac{hf}{0.405K} = \frac{6.626 \times 10^{-34} \times 5.455 \times 10^{14}}{0.405 \times 1.381 \times 10^{-23}} = 64624.54 \text{ kelvin}$$

Q.1.e) Sketch and discuss the basic principle of Fabry Perot resonator with clearing cavity length oscillation condition and active medium gain threshold? [4 Marks]



when sufficient population inversion exists in the amplifying medium the radiation builds up and becomes established as standing waves between the mirrors. These standing waves exist only at frequencies for which the distance between the mirrors is an integral number of half wavelengths. Thus when the optical spacing between the mirrors is L , the resonance condition along the axis of the cavity is given by

$$L = \frac{\lambda q}{2n}$$

It has been indicated that steady-state conditions for laser oscillation are achieved when the gain in the amplifying medium exactly balances the total losses. On each round trip the beam passes through the medium twice. Hence the fractional loss incurred by the light beam is:

$$\text{Fractional loss} = r_1 r_2 \exp(-2\alpha L)$$

Furthermore, it is found that the increase in beam intensity resulting from stimulated emission is exponential. Therefore if the gain coefficient per unit length produced by stimulated emission is \bar{g} cm⁻¹, the fractional round trip gain is given by:

$$\text{Fractional gain} = \exp(2\bar{g}L)$$

Hence: Fractional gain \times Fractional loss = 1

$$\exp(2\bar{g}L) \times r_1 r_2 \exp(-2\bar{\alpha}L) = 1$$

$$\text{and } r_1 r_2 \exp[2(\bar{g} - \bar{\alpha})L] = 1$$

The threshold gain \bar{g}_{th} per unit length may be obtained by rearranging the above expression to give:

$$\bar{g}_{th} = \bar{\alpha} + \frac{1}{2L} \ln \frac{1}{r_1 r_2}$$

Q.1.f) A 66 km single mode optical fiber has a core diameter is 6 μ m and operating at a wavelength of 1300 nm. If a laser source with bandwidth 800 MHz and power 2 W launched into a fiber. compare the threshold optical powers for stimulated Brillouin and Raman scattering within the fiber at the wavelength specified if the measured mean power at the fiber end is 1 mw.

[4 Marks]

$$\alpha_{dB/km} = \frac{10}{L} \log_{10} \frac{P_i}{P_0} = \frac{10}{66 \text{ km}} \log_{10} \frac{2}{1 \times 10^{-3}} = 0.5 \text{ dB/km}$$

The threshold optical power for SRS

we noted that $P_R \gg P_B$

Question Two (25 mark)

Q.2.a) Design a Fabry-Perot cavity for a ruby laser contains a crystal of length L cm with a refractive index of n. The peak emission frequency from the device is 428 THz and the number of longitudinal modes is 3×10^5 . Determine n, L if the separation wavelength is 2 nm.

[4 Marks]

Ans

$$L = \frac{\lambda q}{2n} \text{ and } f = \frac{qc}{2nL}$$

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{545.45 \times 10^{12}} = 0.55 \mu\text{m}$$

$$3 \times 10^5 = \frac{2nL}{\lambda} = \frac{2 \times nL}{0.55 \times 10^{-6}}$$

$$nL = 0.0825 \text{ m} \quad (1)$$

for a ruby laser crystal $n = 1.78$

$$\text{then } L = \frac{0.0825}{1.78} \text{ m} = 4.63 \text{ cm}$$

Q.2.b) Briefly explain the reasons for pulse broadening due to material dispersion in optical fibers and derive its mathematical formulas? [4 Marks]

Dispersion is a data or pulse distortion due to the interference between the adjacent symbols, where the symbols are broadening as they travel a long distance and the delay time difference between the modes, where each mode has a different velocity inside the channel.

$$\sigma_T = (\sigma_c^2 + \sigma_n^2)^{1/2}$$

waveguide dispersion is generally negligible compared with material dispersion in multimode fibers, then $\sigma_c \cong \sigma_m$ and $\sigma_m = \sigma_\lambda L M$, there is no an ideal light source to generate a single light wavelength due to the light beam generated from a source has multiple modes and a group delay is

$$\tau_g = \frac{d\beta}{d\omega} = \frac{1}{c} \left(n_1 - \lambda \frac{dn_1}{d\lambda} \right)$$

$$\tau_m = L\tau_g = \frac{L}{c} \left(n_1 - \lambda \frac{dn_1}{d\lambda} \right)$$

$$\frac{d\tau_m}{d\lambda} = \frac{L\lambda}{c} \left[\frac{dn_1}{d\lambda} - \frac{d^2n_1}{d\lambda^2} - \frac{dn_1}{d\lambda} \right] = \frac{-L\lambda}{c} \frac{d^2n_1}{d\lambda^2}$$

$$M = \frac{1}{L} \frac{d\tau_m}{d\lambda} = \frac{\lambda}{c} \left| \frac{d^2n_1}{d\lambda^2} \right|$$

$$\sigma_m = \sigma_\lambda L M = \sigma_m \cong \frac{\sigma_\lambda L}{c} \left| \lambda \frac{d^2n_1}{d\lambda^2} \right|$$

Q.2.c) A multimode step index fiber has a numerical aperture of 0.3 and a core refractive index of 1.45.

The material dispersion parameter for the fiber is $250 \text{ ps nm}^{-1} \text{ km}^{-1}$ which makes material dispersion the totally dominating chromatic dispersion mechanism. Estimate (a) the total rms pulse broadening per kilometer when the fiber is used with an LED source of rms spectral width 50 nm and (b) the corresponding bandwidth-length product for the fiber. [4 Marks]

(a) The rms pulse broadening per kilometer due to material dispersion is

$$\sigma_m(1 \text{ km}) \cong \frac{\sigma_\lambda L \lambda}{C} \left| \frac{d^2 n_1}{d\lambda^2} \right| = \sigma_\lambda L M = 50 \times 1 \times 250 \text{ ps km}^{-1} = 12.5 \text{ ns km}^{-1}$$

The rms pulse broadening per kilometer due to intermodal dispersion for the step index fiber is

$$\sigma_s(1 \text{ km}) \cong \frac{L(NA)^2}{4\sqrt{3}n_1 C} = \frac{10^3 \times 0.09}{4\sqrt{3} \times 1.45 \times 2.99 \times 10^8} = 29.9 \text{ ns km}^{-1}$$

The total rms pulse broadening per kilometer is

$$\sigma_T = (\sigma_c^2 + \sigma_n^2)^{1/2} = (12.5^2 + 29.9^2)^{1/2} = 32.4 \text{ ns km}^{-1}$$

(b) The bandwidth-length product is

$$B_{opt} \times L = \frac{0.2}{\sigma_T} = \frac{0.2}{32.4 \times 10^{-9}} = 6.2 \text{ MHz km}$$

Q.2.d) How to reduce various types of dispersion in optical fibers?

[4 Marks]

- 1- using a very linewidth optical source to minimize the chromatic dispersion
- 2- using zero material dispersion factor and solitons fiber
- 3- using fiber Bragg grating and optical filters
- 4- compact intermodal dispersion using single mode fiber
- 5- increase the relative refractive index difference.

Q.2.e) Calculate the transmission bit rate for return to zero data format of optical fibers communication system according to International Telecommunications Union (ITU) spectral band designations?

[4 Marks]

For RZ optical pulse coding bit rate = bandwidth

Bandwidth = $f_2 - f_1$ and ITU wavelengths from $1.26 \mu\text{m}$ to $1.675 \mu\text{m}$

$$f_1 = c/\lambda = 3 \times 10^8 / 1.26 \times 10^{-6} = 238.09 \text{ THz}$$

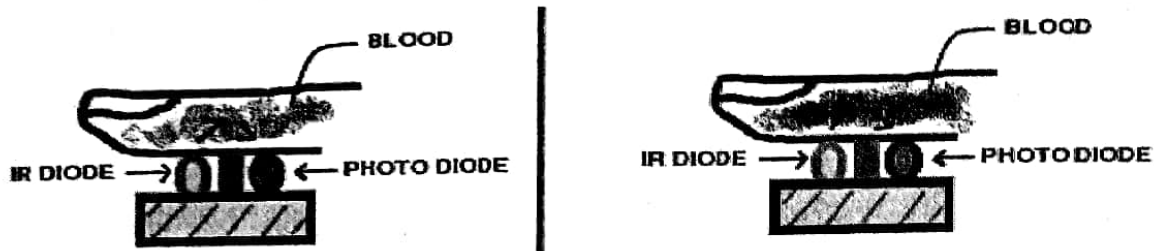
$$f_2 = c/1.675 \mu\text{m} = 3 \times 10^8 / 1.675 \times 10^{-6} = 179.1 \text{ THz}$$

$$\text{Bandwidth} = f_2 - f_1 = 238.09 - 179.1 = 58.99 \text{ THz}$$

Bit rate is 58.99 THz or Tbps

Q.2.f) Design and explain an optical counter to measure a heart beat rate?

[5 Marks]



It is based on the principal of photo-phlethysmography (PPG) which is non-invasive method of measuring the variation in blood volume in tissue using a light source and detector. While the heart is beating, it is actually pumping blood throughout the body, and that makes the blood volume inside the finger artery to change too. This fluctuation of blood can be detected through an optical sensing mechanism placed around the fingertip. The signal can be amplified and is sent to a DSP to indicate the heart beat rate.

A simple design using a block diagram of the optical counter circuit is given in Figure 3. The dc power supply unit supplies a constant 5 volt to infrared light source, infrared light receiver, monostable multivibrator and counter circuit. Light is incident on the finger tip from an infrared light source. The reflected light from the finger tip is received by the infrared light detector. The detector outputs a modulated voltage signal. The heart beat rate can be computed by knowing the time period of the PPG waveform. The monostable multivibrator converts the incoming signal into pulses, which is counted and displayed by the counter and the display respectively.

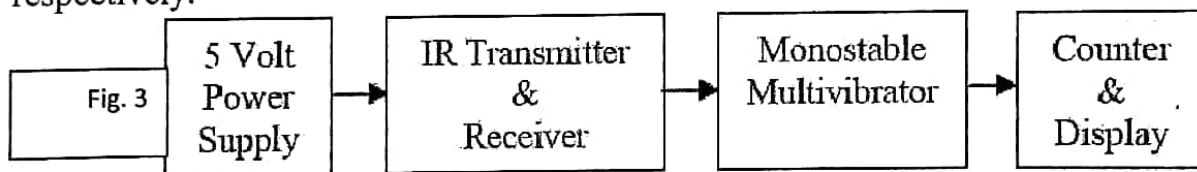


Figure 4 counter which received the analog voltage from a monostable multivibrator to a binary pulses equivalent to the input voltage

