



Course Name: Optoelectronics  
Course Code: ECE399  
Autumn Semester Exam.  
BME Program  
Level 300  
Exam Date: 26 -8-2018  
Allowed Time: 2 Hours



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

**Question One (25 mark)**

- Q.1.a) Drive an expression for the ratio between Einstein's stimulated emission coefficient to spontaneous emission coefficient? And how to make the stimulated emission is dominant? [5 Marks]
- Q.1.b) A photodiode has a quantum efficiency of 65% when photons of energy  $1.5 \times 10^{-19}$  J are incident upon it. [5 Marks]
- (i) At what wavelength is the photodiode operating?
- (ii) Calculate the incident optical power required to obtain a photocurrent of  $2.5 \mu\text{A}$  when the photodiode is operating as described above.
- Q.1.c) Briefly explain the differences between two level, three level and four level system for lasing emission? [5 Marks]
- Q.1.d) Define longitudinal and transverse modes in LASER device? [5 Marks]
- Q.1.e) An injection laser has an active cavity with losses of  $30 \text{ cm}^{-1}$  and the reflectivity of the each cleaved laser facet is 30%. Determine the laser gain coefficient for the cavity when it has a length of  $600 \mu\text{m}$ . [5 Marks]

**Question Two (25 mark)**

- Q.2.a) A 66 km single mode optical fiber has a core diameter is  $6 \mu\text{m}$  and operating at a wavelength of  $1300 \text{ nm}$ . If a laser source with bandwidth  $800 \text{ MHz}$  and power  $2 \text{ W}$  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  $1 \text{ mw}$ . [5 Marks]
- Q.2.b) A multimode graded index fiber exhibits total pulse broadening of  $0.1 \mu\text{s}$  over a distance of  $15 \text{ km}$ . Estimate: [5 Marks]
- i- The maximum possible bandwidth on the link assuming no Intersymbol Interference.
- ii- The pulse dispersion per unit length

iii- The bandwidth-length product for the fiber.?

**Q.2.c)** State the important performance and compatibility requirements for a photodetectors? [3 Marks]

**Q.2.d)** A silica optical fiber with a core diameter large enough to be considered by ray theory analysis has a core refractive index of 1.50 and a cladding refractive index of 1.47. Determine: (a) the critical angle at the core-cladding interface; (b) the NA for the fiber; (c) the acceptance angle in air for the fiber. [3 Marks]

**Q.2.e)** Flexible endoscopes are expensive and relatively fragile. what are the attention to care it? [3 Marks]

**Q.2.f)** State the solution of the following common problems occurs in flexible Endoscopes. i. Out of focus ii. No insufflations [3 Marks]

**Q.2.g)** A graded index fiber has a core with a parabolic refractive index profile which has a diameter of 50  $\mu\text{m}$ . The fiber has a numerical aperture of 0.2. Estimate the total number of guided modes propagating in the fiber when it is operating at a wavelength of 1  $\mu\text{m}$ . [3 Marks]

*My best wishes to all of you!*

***Dr. Bedir Yousif***

Q-1-a

$$\frac{N_1}{N_2} = \left( \frac{g_1 \exp(-E_1/KT)}{g_2 \exp(-E_2/KT)} \right) = \frac{g_1}{g_2} \exp((E_2 - E_1)/KT) = \frac{g_1}{g_2} \exp(hf/KT)$$

$$R_{12} = N_1 \rho_f B_{12}$$

$$R_{21} = N_2 A_{21} + N_2 \rho_f B_{21}$$

It follows that:

$$\rho_f = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}} = \frac{A_{21}/B_{21}}{N_1 B_{12}/N_2 B_{21} - 1} = \frac{A_{21}/B_{21}}{(g_1 B_{12}/g_2 B_{21}) \exp(hf/KT) - 1}$$

$$\rho_f =$$

The radiation spectral density for a black body radiating

$$\rho_f = \frac{8\pi hf^3}{C^3} \left[ \frac{1}{\exp(hf/KT) - 1} \right]$$

Comparing Eqns, we obtain the Einstein relations:

$$B_{12} = \left( \frac{g_2}{g_1} \right) B_{21}$$

$$\frac{\text{stimulated emission rate}}{\text{spontaneous emission rate}} = \frac{B_{21} \rho_f}{A_{21}} = \frac{1}{\exp\left(\frac{hf}{KT}\right) - 1}$$

Q1-b-

$$\lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34} \times 2.998 \times 10^8}{1.5 \times 10^{-19}} = 1.32 \mu m$$

The photodiode is operating at a wavelength of 1.32  $\mu m$ .

(b)

$$R = \frac{\eta e}{hf} = \frac{0.65 \times 1.602 \times 10^{-19}}{1.5 \times 10^{-19}} = 0.694 \text{ Aw}^{-1}$$

$$R = \frac{I_p}{P_o}$$

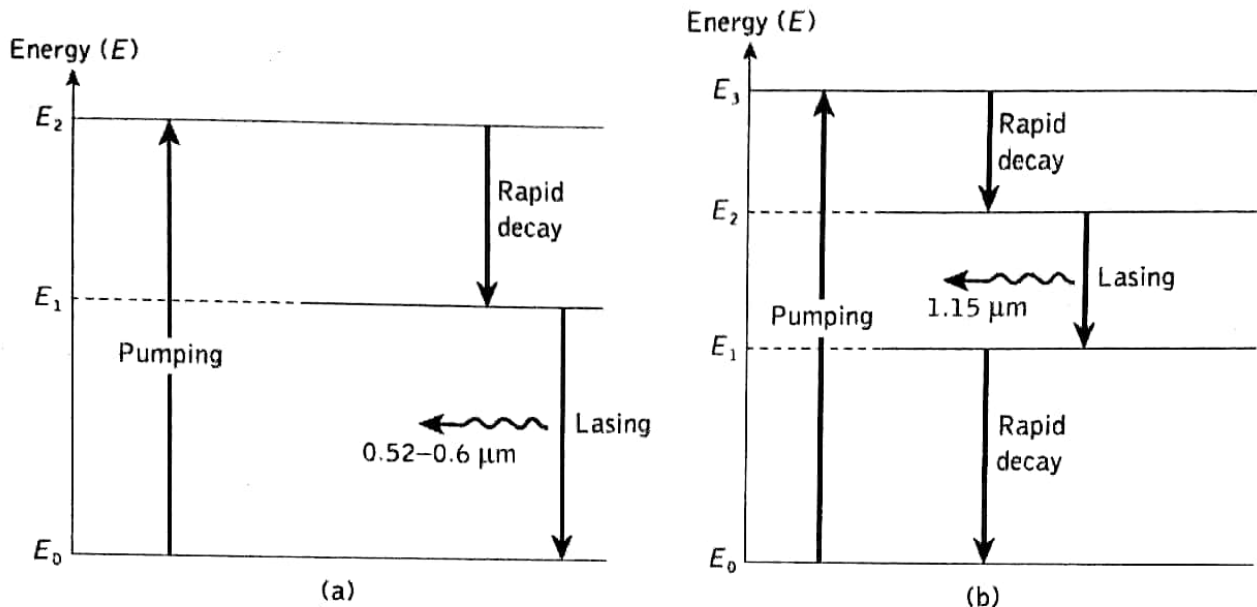
Therefore:

$$P_o = \frac{2.5 \times 10^{-6}}{0.694} = 3.6 \mu W$$

Q1-c: Two level system

In the former case atoms are excited into the higher energy state through stimulated absorption. However, the two-level system where absorption rate equal the emission rate, this is does not suitable for population inversion.

Three level and four level systems are suitable for population inversion. The energy-level diagrams for two such systems, which correspond to two nonsemiconductor lasers are shown in fig. below



both systems display a central metastable state in which the atoms spend an unusually long time

It is from this metastable level that the stimulated emission or lasing takes place. The three-level system in (Figure (a)). Initially, the atomic distribution will follow Boltzmann's law. However, with suitable pumping the electrons in some of the atoms may be excited from the ground state into the higher level  $E_2$ . Since  $E_2$  is a normal level the electrons will rapidly decay by nonradiative processes to either  $E_1$  or directly to  $E_0$ . Hence empty states will always be provided in  $E_2$ . The metastable level  $E_1$  exhibits a much longer lifetime than  $E_2$  which allows a large number of atoms to accumulate at  $E_1$  and population inversion occurs between levels  $E_1$  and  $E_0$ . A drawback with the three-level system such as the ruby laser is that it generally requires very high pump powers because the terminal state of the laser transition is the ground state. Hence more than half the ground state atoms must be pumped into the metastable state to achieve population inversion.

By contrast, a four-level system such as the He-Ne laser illustrated in (Figure b) is characterized by much lower pumping requirements. In this case the pumping excites the atoms from the ground state into energy level  $E_3$  and they decay rapidly to the metastable level  $E_2$ . However, since the populations of  $E_3$  and  $E_1$  remain essentially unchanged, a small increase in the number of atoms in energy level  $E_2$  creates population inversion, and lasing takes place between this level and level  $E_1$ .

**Q1-d:**

longitudinal modes in LASER device: are propagated along the cavity axis and is used to determine the number of modes and frequency separation between the modes. but transverse modes in LASER device are propagated perpendicular to the cavity axis and is used to determine the spot size of laser

**Q1-e:**

The threshold gain per unit length where  $r_1 = r_2 = r$  is given

$$\bar{g}_{th} = \bar{\alpha} - \frac{1}{2L} \ln \frac{1}{r_1 r_2} = 30 + \frac{1}{0.06} \ln \frac{1}{0.3} = 50 \text{ cm}^{-1}$$

**Q2-a**

A He-Ne laser, operating at 632.8 nm has an output power of  $P=1 \text{ mW}$ . The power in the cavity is '99P. a- Calculate the ratio between Einstein's stimulated emission coefficient to spontaneous emission coefficient? b- Refractive index of medium c- Determine the cavity gain if losses inside the cavity is  $20 \text{ cm}^{-1}$  and the frequency separation is 3 GHz. d- What is the effective blackbody temperature of laser beam in cavity if the radiation spectral density is  $2.8 \times 10^{-12} \text{ J} \cdot \frac{\text{s}}{\text{m}^3}$ . e- Estimate the ratio between Einstein's stimulated emission coefficient to stimulated absorption coefficient if the degeneracies in lower and upper level are 41 and 43 respectively.

$$\lambda = 632.8 \text{ nm}, r = 0.99, B_{12} = \left(\frac{g_2}{g_1}\right) B_{21}$$

$$\frac{\text{stimulated emission rate}}{\text{spontaneous emission rate}} = \frac{B_{21} \rho_f}{A_{21}} = \frac{1}{\exp\left(\frac{hf}{KT}\right) - 1}$$

$$\frac{B_{21}}{A_{21}} = \frac{1}{\rho_f [\exp\left(\frac{hf}{KT}\right) - 1]} = \frac{C^3}{8\pi hf^3} = 0.152 \text{ -----} \rightarrow a$$

$$L = \frac{c}{2n\delta f} = 0.0125 \text{ cm}$$

$$r_1 = r_2 = r = \left(\frac{n-1}{n+1}\right)^2 = 0.99$$

so that  $n=399$  and  $L=0.0125 \text{ cm}$

$$\bar{g}_{th} = \bar{\alpha} + \frac{1}{2L} \ln \frac{1}{r_1 r_2} = 20 + \frac{1}{0.0125} \ln \frac{1}{0.99} \cong 20.8 \text{ cm}^{-1} \rightarrow b$$

$$2.8 \times 10^{-12} = \frac{A_{21}/B_{21}}{\exp\left(\frac{hf}{kT}\right) - 1} \rightarrow T = 800 \text{ K} \rightarrow c$$

$$\frac{B_{21}}{B_{12}} = \left(\frac{g_1}{g_2}\right) = \frac{41}{43} = 0.953$$

**Q2-b:** A multimode graded index fiber exhibits total pulse broadening of 0.1  $\mu\text{s}$  over a distance of 15 km. Estimate:

- The maximum possible bandwidth on the link assuming no Intersymbol Interference.
- The pulse dispersion per unit length;
- The bandwidth-length product for the fiber.?

for return to zero pulses) assuming no ISI

$$B_{\text{opt}} = B_T = \frac{1}{2\tau} = \frac{1}{0.2 \times 10^{-6}} = 5 \text{ MHz}$$

- The dispersion per unit length may be acquired simply by dividing the total dispersion by the total length of the fiber:

$$\text{Dispersion} = \frac{0.1 \times 10^{-6}}{15} = 6.67 \text{ ns km}^{-1}$$

- The bandwidth-length product may be obtained in two ways. Firstly by simply multiplying the maximum bandwidth for the fiber link by its length. Hence:

$$B_{\text{opt}} L = 5 \text{ MHz} \times 15 \text{ km} = 75 \text{ MHz km}$$

Alternatively, it may be obtained from the dispersion per unit length using Eq. (3.10) where:

$$B_{\text{opt}} L = \frac{1}{2 \times 6.67 \times 10^{-6}} = 75 \text{ MHz km}$$

**Q2-c:** Define the important performance and compatibility requirements for detectors?

- High sensitivity at the operating wavelengths.
- High fidelity. To reproduce the received signal waveform with fidelity, for analogy transmission the response of the photodetector must be linear with regard to the optical signal over a wide range.

3. Large electrical response to the received optical signal. The photodetector should produce a maximum electrical signal for a given amount of optical power; that is, the quantum efficiency should be high.
4. Short response time to obtain a suitable bandwidth. Current single-channel, singlemode fiber systems extend up to many tens of gigahertz. However, it is apparent that future wavelength division multiplexed systems (see Section 12.9.4) will operate in the multiple terahertz ( $10^{12}$  Hz) range, and possibly above.
5. A minimum noise introduced by the detector. Dark currents, leakage currents and shunt conductance must be low. Also the gain mechanism within either the detector or associated circuitry must be of low noise.
6. Stability of performance characteristics. Ideally, the performance characteristics of the detector should be independent of changes in ambient conditions. However, the detectors currently favored (photodiodes) have characteristics (sensitivity, noise, internal gain) which vary with temperature, and therefore compensation for temperature effects is often necessary.
7. Small size. The physical size of the detector must be small for efficient coupling to the fiber and to allow easy packaging with the following electronics.
8. Low bias voltages. Ideally the detector should not require excessive bias voltages or currents.
9. High reliability. The detector must be capable of continuous stable operation at room temperature for many years.
10. Low cost. Economic considerations are often of prime importance in any large scale communication system application.

Q2-d: *Critical angle*  $= \phi_c = \sin^{-1} \left( \frac{n_2}{n_1} \right) = \sin^{-1} \left( \frac{1.47}{1.5} \right) = 78.5^\circ$

(b) The NA is:  $N_A = \sqrt{n_1^2 - n_2^2} = \sqrt{1.5^2 - 1.47^2} = 0.3$

(c) The acceptance angle in air  $\theta_a$  is given by

$$\theta_a = \sin^{-1} N_A = \sin^{-1} 0.3 = 17.4^\circ$$



Q2-e: Flexible endoscopes are expensive and relatively fragile. Attention to care is important.

1. The light fibers are fragile and easily broken. Coil the endoscope into gentle curves, rather than folding it in acute angles. Do not drop the endoscope, allow a wheeled cart to roll over it, or allow the patient to bite down on the endoscope.
2. Avoid extreme angulation of the tip wherever possible. Do not force biopsy forceps or other instruments down the channel when the tip is sharply angulated, as damage to the biopsy channel may result.
3. Ensure that polypectomy snares and sclerosing needles are fully withdrawn into the sheath before passing through the channel. Lubricate instruments with a suitable lubricant to facilitate passage.
4. The outer coating of the endoscope is delicate, particularly in the region near the tip. A rubber sheath, designed to flex as the tip bends, covers this region of the endoscope.
5. After each use, wash off any gross contamination and suction water through the endoscope. Do not allow blood, mucus, stool, or other foreign matter to dry on the endoscope or in the channels or valves.
6. Endoscopes are rarely actually sterilized. Generally high-level disinfection with a chemical agent (such as glutaraldehyde) is used. Disinfection does not work well when foreign matter (mucus, blood, enteric contents) are present. Therefore, the endoscope must be mechanically cleaned before disinfection. Many endoscopy suites use automated cleaners that rapidly wash, disinfect, and rinse the endoscope.

Ultrasonic cleaners are available in some units.

7. Ethylene oxide gas sterilization is an option, but it requires an overnight cycle. Newer methods of sterilization and newer endoscopes that are more tolerant of sterilizing conditions are being developed. Be careful to follow the manufacturer's instructions for sterilization to avoid potentially severe damage to the endoscope.

Q2-f:



Problem	Check the following
Out of focus	1. Adjust focus ring 2. Fiberoptic scope—clean lens
No irrigation	1. Water bottle contains water 2. Water bottle connected to umbilical cord 3. Connection tight 4. Lid of water bottle screwed on tightly 5. Power turned on 6. Valve stuck or occluded
No insufflation	1. Umbilical cord firmly seated into light source and screwed in if necessary 2. Power turned on 3. Valve stuck or occluded

Q2-g:

the normalized frequency for the fiber is:

$$V = \frac{2\pi}{\lambda} a (N_A) = \frac{2\pi}{\lambda} a n_1 (2\Delta)^{0.5} = \frac{2\pi \times 25 \times 10^{-6} \times 0.2}{1 \times 10^{-6}} = 31.4$$

The mode volume for parabolic profile:

$$M_g = \left( \frac{\alpha}{\alpha + 2} \right) \frac{V^2}{2} = \frac{V^2}{4} = \frac{986}{4} = 247$$