



96571
Course Name: Optoelectronics
Course Code: ECE491
Spring Semester Exam.
BME Program
Level 300
Exam Date: 22-5-2017
Allowed Time: 2 Hours



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

Question One (25 mark)

Q.1.a) Define: Population inversion- Numerical aperture – LASER oscillation conditions- quantum efficiency of LASER diode and photodetector- stimulated and spontaneous emission of light. [5 Marks]

Q.1.b) State the main differences between [10 Marks]

- i. PIN photodiode and Avalanche photodiode.
- ii. LASER diode and LED
- iii. Optical fiber Rayleigh and Raman scattering.
- iv. Heterojunction and homojunction of p-n diode.
- v. Direct and indirect bandgap semiconductors.

Q.1.c) A single-mode step index fiber with a core refractive index of 1.49 has a critical bending radius of 10.4 mm when illuminated with light at a wavelength of $1.30 \mu\text{m}$. If the cutoff wavelength for the fiber is $1.15 \mu\text{m}$ calculate its relative refractive index difference. [5 Marks]

Q.1.d) A p-n photodiode has a quantum efficiency of 50% at a wavelength of $0.9 \mu\text{m}$. Calculate: (i) its responsivity at $0.9 \mu\text{m}$; (ii) the received optical power if the mean photocurrent is 10^{-6} A ; (iii) the corresponding number of received photons at this wavelength. [5 Marks]

Question Two (25 mark)

Q.2.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.2.b) 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. [5 Marks]

Q.2.c) Calculate the photons rate of a photodetector that has absorption coefficient of $5 \times 10^5 \text{ cm}^{-1}$, the width of absorption region is $500 \mu\text{m}$, reflection of surface 0.4 and the photocurrent of $5 \mu\text{A}$. [5 Marks]

Q.2.d) (i) A multimode step index fiber gives a total pulse broadening of 95 ns over a 5 km length. Estimate the bandwidth-length product for the fiber when a nonreturn to zero digital code is used. [2 Marks]

(ii) A single-mode step index fiber has a bandwidth-length product of 10 GHz.km. Estimate the rms pulse broadening over a 40 km digital optical link without repeaters consisting of the fiber, and using a return to zero code. [2 Marks]

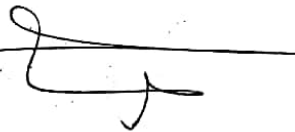
Q.2.e) What is the function and structure of Endoscopy instrument? [3 Marks]

Q.2.f) State the solution of the following common problems occurs in flexible Endoscopes. i. No light at the distal end ii. No irrigation [3 Marks]



My best wishes to all of you!

Dr. Bedir Yousif



Population inversion

The main condition for lasing emission by making the carriers density in upper energy levels greater than carriers density in lower energy levels.

→ Numerical aperture : $NA = \sqrt{n_1^2 - n_2^2}$
an important parameter of optical fiber determines the ability of fiber core to confinement of light

→ LASER oscillation conditions

* Cavity length $L = \frac{\lambda g}{2n}$

* Active medium gain $g \geq g_{th}$

$$g_{th} = \alpha + \frac{1}{2L} \ln \frac{1}{r_1 r_2}$$

* population inversion must be satisfied

→ Quantum efficiency of LASER

$$\eta = \frac{\text{rate of stimulated emission photon}}{\text{rate of stimulated of pumping electrons}}$$

Quantum efficiency of photodiode

$$\eta = \frac{\text{rate of collected electrons}}{\text{rate of collected incident photon}}$$

→ Stimulated emission : every electron-hole recombination generates or more than one photon that has the same phase and wavelength (Coherent) as in LASER

[2]

Spontaneous emission energy $e-h$ recombination generates one photon only in random manner (incoherent light) as in LED.

Q-6 main differences between

PIN photodiode

① a semiconductor photodiode with no internal photocurrent gain

② low cost

③ low o/p current

④ low reverse bias voltage

⑤ low responsivity

APD

a semiconductor photodiode with internal current gain

high cost
high o/p current

high reverse bias voltage

high responsivity (A/W)

LASER

① Stimulated emission of light (Coherent)

② high o/p power

③ polarized light

④ narrow spectral linewidth

⑤ low dispersion

⑥ easy to coupled with optical fiber

LED

Spontaneous emission of light (incoherent)

low o/p power

unpolarized light

large spectral line width

large dispersion

coupled with fiber with some power loss

3

(iii) Rayleigh scatt. Raman scatt.

→ linear (elastic) scatt. nonlinear (inelastic) scatt.

→ no frequency shift there is a frequency shift.

→ scattering occurs in all directions scattering occurs in forward and backward direction

→ it results from inhomog. of random distribution of atoms compared with light wavelength usually occurs at high ip power

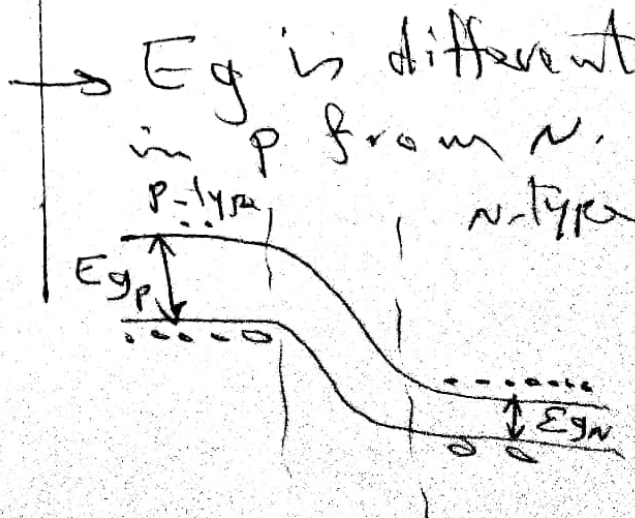
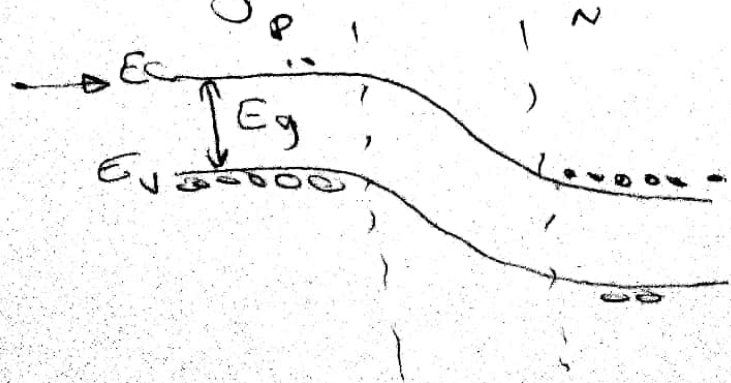
→
$$I_R = \frac{8\pi^3 n^8 p^2 R_e K T F}{3 \lambda^4}$$

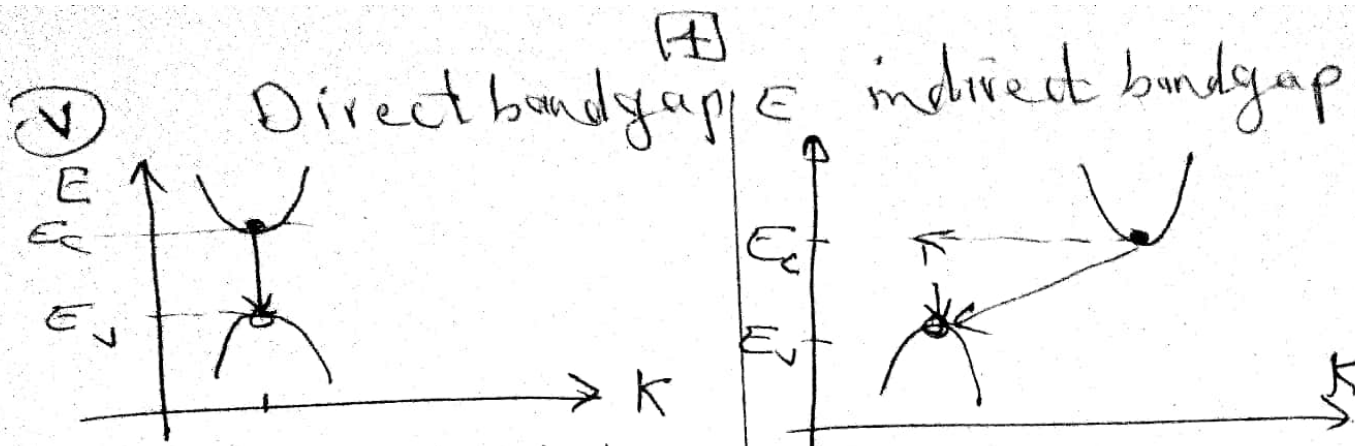
$$I_R = 5.9 \times 10^{-2} \lambda^2 I \propto \lambda^4$$

iv Homojunction PN diode Heterojunction

→ made of single atom crystal of p and n type (from the same material) made of different materials for p and n

→ E_g is constant E_g is different in p from n.





has a small lifetime of carriers recombine such as GaAs, InAs

has a large lifetime such as Si, Ge

A momentum k or wave vector is the same of electrons in C.B and holes in V.B \rightarrow k is different for electrons in C.B from holes in V.B during the recombination process.

P1c0 SMSF $n_1 = 1.49$

$$RCS = 10.4 \text{ nm} = \frac{20 \lambda (2.748 - 0.286 \lambda^3)}{(n_1 - n_2)^{3/2}}$$

$\lambda = 1.3 \mu\text{m}$ $\lambda_c = 1.15 \mu\text{m}$

Then $n_1 - n_2 = 0.007$ so

$$n_2 = 1.49 - 0.007 = 1.483$$

$$NA = \sqrt{n_1^2 - n_2^2} = 0.1443$$

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} = \frac{(0.1443)^2}{2(1.49)^2} = 0.0047$$

P1d0 PD : $\xi = 0.5$; $\lambda = 0.9 \mu\text{m}$

$R = ?$ $P_0 = ?$ $r_p = ?$ $I_p = 10 \text{ A}$

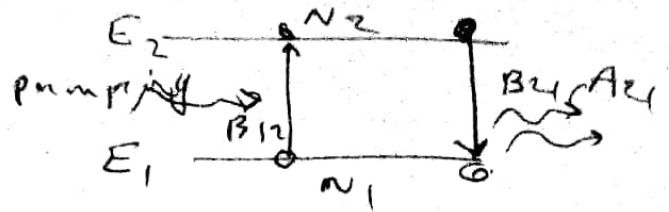
Ans (i) $R = \frac{\xi e \lambda}{hc} = 0.3622 \text{ A/W}$

(ii) $P_0 = \frac{I_p}{R} = 10 / 0.3622 = 27.6 \mu\text{W}$

(iii) $r_p = \frac{r_e}{\xi} = \frac{I_p / e}{\xi} = 12.5 \times 10^{12} \text{ photons/sec}$

[5]

$$\frac{P_{2 \rightarrow 1}}{A_{21}} = \frac{B_{21}}{A_{21}} = ?$$



→ population of two energy levels

$$\frac{N_1}{N_2} = \frac{g_1}{g_2} \exp\left(\frac{hf}{kT}\right)$$

→ absorption rate $R_{12} = N_1 \rho_f B_{12}$

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

at equilibrium $R_{12} = R_{21}$

$$N_1 \rho_f B_{12} = N_2 A_{21} + N_2 \rho_f B_{21}$$

$$\text{and } \rho_f = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}}$$

$$= \frac{A_{21} / B_{21}}{\frac{N_1}{N_2} \frac{B_{12}}{B_{21}} - 1} \rightarrow \text{I}$$

The spectral of energy radiation from black body is ρ_f

$$\rho_f = \frac{8\pi hf^3}{c^3} \rightarrow \text{II}$$

Things by comp. I with $\left(\exp\left(\frac{hf}{kT}\right) - 1\right)$ $\rightarrow \text{II}$

$$\text{and } \frac{B_{12}}{A_{21}} = \frac{\left(\frac{g_2}{g_1}\right) B_{21}}{8\pi hf^3}$$

$$\text{or } \boxed{\frac{B_{21}}{A_{21}} = \frac{c^3}{8\pi hf^3}}$$

stimulated emission can be maximize by

- ① increasing the population inversion
- ② using an active medium with high
- ③ reduce the generated temperature

P2-b $L = 350 \mu m$ $r_1 = 0.5$ $r_2 = 0.65$
 $J = 2\pi \times 10^3 \frac{A}{cm^2}$; $\beta = 22\pi \times 10^3 \frac{cm}{A}$

Ans. $\alpha = 2$
 $J = \frac{1}{\beta} \left[\alpha + \frac{1}{2L} \ln \frac{1}{r_1 r_2} \right]$

$\alpha = J \cdot \beta - \frac{1}{2L} \ln \frac{1}{r_1 r_2}$
 $= 44 \cdot \frac{1}{2(350) \times 10^3} \ln \frac{1}{(0.5)(0.65)}$
 $= 28 \text{ cm}^{-1}$

P2-c $r_p = 2$; $I_p = 5 \text{ mA}$

$\alpha_0 = 5 \times 10^5 \text{ cm}^{-1}$; $r = 0.4$
 $d = 500 \mu m = 500 \times 10^{-6} m = 5 \times 10^{-4} m$

Ans. $r_p = \frac{P_0}{h f}$

$I_p = r_p \cdot e(1-r) [1 - \exp(-\alpha_0 d)]$

$\therefore r_p = \frac{I_p}{e(1-r) [1 - \exp(-\alpha_0 d)]}$
 $= \frac{5.21 \times 10^{13} \text{ photons/sec}}{e(1-r) [1 - \exp(-\alpha_0 d)]}$

P2-d $(i) C = 95 \text{ nF}$ $L = 5 \text{ km}$

$B \cdot L = 2$ for NRZ

Ans. $B_T = \frac{1}{2C} = 5.26 \text{ Mbps}$

$B = \frac{B_T}{2} = 2.63 \text{ MHz}$

$B \cdot L = 2.63 \times 5 = 13.158 \text{ MHz}$
 $\#$

(ii) SMF

[7]

$$B.L = 10 \text{ GHz} \cdot \text{km}$$

$$L = 40 \text{ km for RZ}$$

$$\alpha = 2$$

Ans. $\beta = \frac{10 \text{ GHz} \cdot \text{km}}{40 \text{ km}} = 250 \text{ MHz}$

$$B_T = B = 250 \text{ Mbps}$$

$$\gamma = \frac{0.2}{B_T} = \frac{0.2}{250 \text{ Mbps}} = 800 \text{ ps}$$

Q2-e

fn. of endoscopy is to viewing or visualizing the internal organs and diagnosis and removing some alien parts from human body.

* main components of endoscopy :-

1- light guide (optical fibers) tube

2- water jet tube

3- Air/water tube

4- objective lens and CCD unit

5- Biopsy channel.

Q2-f problem
no light at the
distal end

Solution & check:
The following
1- light source plugged in and turned on.
2- light source ignited
3- Bulb burned out.
4- not in standby mode

(8)

5 - lens at distal tip is dirty

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.

