UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: October 2019

Module Number: EE5305 **Module Name: Sensors, Transducers and Measurement Techniques**

[Three Hours]

[Answer **all questions**, each question carries **10 marks**]

Q1 a) State the values and SI units for the following parameters:

i) Speed of sound in air.
ii) Density of air.
iii) Speed of sound in vacuum.
iv) Speed of sound in water.
v) Density of water.
vi) Audible frequency range in air.

[1.5 Marks]

b) i) "A piezoelectric disc of crystalline material in its normal form is not piezoelectric."
Explain this statement and the method used to make the piezoelectric disc have net piezoelectricity.

ii) State the 1-Dimensional piezoelectric equations and define the parameters.

iii) Evaluate the resonance frequency of a PZT 5A piezoelectric disc of thickness 2.0 mm given that the compressional speed in the material is 4350 ms-1.

iv) Give the equivalent circuit for a piezoelectric disc and show the resonant frequency in the input impedance characteristics.

v) Sketch the structure of a high resolution acoustic transducer and name its main features.

[4.5 Marks]

c) i) A transducer is made with the piezoelectric disc in b) iii) for high resolution underwater applications.

I. Evaluate the best possible resolution in time and distance.
II. The transducer used in pulse-echo mode returns a target reflection 135 ms after the transmitted signal. Calculate the distance to the target.

ii) In underwater Non Destructive Testing (NDT) applications explain why the transducer is tilted above a certain critical angle for clarity of signal interpretation.

iii) Synthesize the transmitted wavefront for a linear four (4) piezoelectric element array when the array elements are excited in phase.

iv) Synthesize the excitation signals for the array elements in c) iii) for the transmitted wavefront to be tilted by 10°.

[4 Marks]

Q2 a) i) Sketch the frequency response [Photopic luminous efficiency function $V(\lambda)$ vs λ] of the human eye and mark the positions of the three primary colours.

ii) State the meaning of the acronyms LED and LASER.

iii) State a coherent and an incoherent source in electro-optics.

iv) The energy of an electron can be expressed as $E = \hbar^2k^2/2me^*$. Define the parameters.

v) State the Conservation Laws that must be always satisfied in optical band-to-band transitions.

vi) Sketch simple Wavevector vs. Energy diagrams to illustrate a direct and an indirect gap semiconductor.

vii) State the energy and wavevector relationships for direct gap band-to-band transitions.

viii) Nitrite compounds have band gap energies ranging from 1.9eV to 6.2eV. Calculate the spectral range in units of nm.

Take: $1\ eV = 1.602 \times 10^{-19}$ Joules

Planck's constant $h = 6.6261 \times 10^{-34}\ m^2kgs^{-1}$

Speed of light $c = 3 \times 10^8\ ms^{-1}$

ix) State the significance of the results in viii)

[5 Marks]

b) i) Sketch the energy band diagram, excess carrier distribution, refractive index and optical field distribution for an optical pn homojunction LED in forward bias.

ii) Considering the diffusion of charge carriers across the pn junction, describe the active layer in a LED.

iii) Sketch the structure of a standard LED with a dome lens and define the component parts.

iv) Define the power-current relation for a LED.

v) Sketch the power-current (P-I) characteristics and the emission spectral density of an LED and interpret the shape of the curves.

[5 Marks]

Q3 a) i) Explain the band-to-band transitions for a LED and a LASER.

ii) The absorption coefficient $\alpha(v)$ contributed by direct band-to-band transitions in a semiconductor is given by

$\alpha(v) = \alpha_0(v)\ [\ f_v(E_1) - f_c(E_2)]$, where $\alpha_0(v)$ is the intrinsic semiconductor absorption coefficient.

I. Describe the terms $f_v(E_1)$ and $f_c(E_2)$.

II. Formulate an expression for the gain coefficient $g(v)$.

III. Describe a practical definition for population inversion.

[3.5 Marks]

b) i) Sketch the energy band structure of a p - N heterojunction where p and N denote P type small gap and N type large gap semiconductors respectively.

ii) Sketch the energy band diagram, excess carrier distribution, refractive index and optical field distribution for a double heterojunction.

iii) State the conditions for a LASER to oscillate at a particular frequency.

iv) Sketch two stripe geometry LASERs that achieve the oscillator conditions in b) iii).

[4 Marks]

c) i) Sketch the power- current (P-I) characteristics and the emission spectral density of a single mode LASER and interpret the shape of the curves.

ii) State and compare the parameters that determine the modulation speeds of a LASER and an LED.

[2.5 Marks]

Q4 a) i) Define the mean value of a signal s.

ii) Define the noise s_n of a signal s.

iii) State the reason for measuring the noise of a signal from its average power.

iv) Define the rms (root mean square) value of noise.

v) Define the SNR (Signal to Noise Ratio) in dB of a signal.

[2.5 Marks]

b) i) Explain the principle under which a photodetector operates.

ii) Formulate an expression for the photo current i_{ph} for a photodetector without noise.

iii) Explain the following statements:

I. The power P_s of the optical signal and the number of photons S received in a given time interval T fluctuate randomly around their average values $\overline{P_s}$ and $\overline{S}$.

II. With a quantum efficiency η_e, where $0 \leq \eta_e \leq 1$, the number of photoelectrons generated is only a fraction of the photons received by the detector.

iv) Formulate the shot noise component for a photodetector for incident optical power P_s if the mean square noise in the number of photogenerated carriers is equal to the mean of the charge carriers.

[5 Marks]

c) i) Sketch a typical input optical power vs output photocurrent characteristics for a photodetector and define the following in the sketch.

I. Noise Equivalent Power (NEP)

II. Responsivity (Я)

III. Dynamic Range (DR)

ii) Sketch the characteristics for a PN junction photodetector and define the two modes of operation.

[2.5 Marks]

Q5 a) Explain the difference between a voltage amplifier and a power amplifier.

[1 Mark]

b) Explain crossover distortion in class B amplifiers.

[1 Mark]

c) A transformer coupled class A power amplifier draws a current of 200 mA from the collector supply of +10 V when no signal is applied to it. Determine the,

i) Maximum output power.
ii) Maximum collector efficiency.
iii) Power rating of the transistor.
iv) If the load connected across the transformer secondary is 2 Ω and the transformer ratio 5:1, comment on the impedance matching.

[5 Marks]

d) i) If a measured angle is $\theta = 20 \pm 3^{o}$, find $\cos(\theta)$ with its uncertainty.

ii) A digital voltmeter reads voltages to the nearest thousandth of a volt. What will be its percent uncertainty in measuring a voltage of 3 volts?

iii) The height l of an inaccessible tall tree is estimated by measuring three other lengths l_1, l_2 and l_3 in terms of which $l = l_1{*}l_2 / l_3$. Find the uncertainty of l if

$l_1 = 200 \pm 2$ cm, $l_2 = 5.5 \pm 0.1$ cm and $l_3 = 10.0 \pm 0.4$ cm.

[3 Marks]