UNIVERSITY OF RUHUNA

Faculty of Engineering

End Semester 5 Examination in Engineering: March 2022

Module Number: EE5305 **Module Name: Sensors,Transducers and Measurement Techniques(N/C)**

[Three Hours]

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

Q1. a). i. Define what is a sensor and a transducer with an example for each of them. [1 mark]

ii. Specify three (3) semiconductor optical transducers. [1 mark]

iii. Briefly explain why Silicon (Si) is an indirect band gap semiconductor with the aid of an energy band diagram. [1 mark]

iv. State one (1) similarity and two (2) differences between a photon and a phonon. [1 mark]

v. State two (2) requirements for LASER operation and briefly explain each of them. Your explanation must also include how each of the requirements is practically realized in a LASER? [1 mark]

vi. Draw the energy band diagram and the optical field distribution along the direction x for PpN double hetero-structure given in Figure Q1(a) under forward bias condition. [1 mark]

vii. State the two (2) types of resonant cavities in semiconductor LASERs and briefly explain how they are implemented? [1 mark]

b). An edge emitting semiconductor LED is configured in Forward bias to emit photons having a forward bias current of 1 mA and a forward bias Voltage of 0.8 V. The power conversion efficiency of the LED is 0.7. The LED is constructed as shown in Figure Q1(b) such that it will have a solid angle of $\pi/2$ for the escape cone and a transmittance of 0.8 for the epoxy dome lens.

i. State the coherency and polarization of the photons emitted by the LED. [0.5 marks]

ii. State the type of emission which causes the photons to be emitted. [0.5 marks]

iii. Find the escape efficiency of the LED. [1 mark]

iv. Find the optical output power emitted out from the epoxy dome lens. [1 mark]

Q2. a). i. State the two (2) types of effects that can occur in a Piezoelectric acoustic transducer and briefly explain each of them. [1 mark]

ii. Specify three (3) semiconductor optical transducers. [1 mark]

iii. Briefly explain how a dynamic microphone operates. [1 mark]

iv. State the three (3) types of elastic waves. [1 mark]

v. Provide an example for a piezoelectric material. State the property that the crystalline structure should have in order for the crystal to be piezoelectric? [1 mark]

b). A piezoelectric disc transducer operates in thickness mode inside water. The thickness of the disc when no electric field is applied or no mechanical stress is applied is 2.5 mm. Assume that the speed of transmission of a compressional wave in water is 1500 ms^{-1}.

i. Find the oscillating frequency (resonance frequency) of the electric field that is required to be applied in order to get maximum mechanical vibrations from the transducer at the same frequency? [0.5 marks]

ii. Figure Q2(bI) shows the equivalent electrical circuit of the piezoelectric transducer. Find the capacitance of the capacitor C1. [0.5 marks]

iii. Now, a backing is fixed to one side of the disc transducer, and it is used to find the height of a cube immersed in seawater as shown in Figure Q2(bII) using immersion testing. Assume that the acoustic impedance of the seawater and the piezoelectric material are nearly equal ($Z_{sea} = Z_{pie}$). Further, assume that the acoustic impedance of the cube and that of the sea floor are nearly equal ($Z_{cub} = Z_{floor}$) and the acoustic impedance of the sea floor is much higher than that of water (Z_{cub}>> Z_{sea}). By referring to the reflected signals shown in the acoustic transducer ~~as shown~~ in Figure Q2(bIII), answer the following questions.

I. State the purpose of the backing used in the transducer?

[0.5 marks]

II. Find the depth of the sea floor? [1 mark]

III Find the height of the cube? [0.5 marks]

iv. An angled probe constructed from perspex shown in Figure Q2(bIV) is used to detect defects in a solid constructed from Aluminium. The velocity of a compressional wave in Perspex is 6500 ms^{-1} and the velocity of a Compressional and Shear waves in Aluminium is 15000 ms^{-1at} and 9500 ms^{-1} respectively.

I. Specify how inside defects and surface defects of a given solid (Aluminium) can be detected by changing the probe's angle of incidence (i)? [1 mark]

II. Find the angle at which the probe should be placed in order to detect surface defects? [1 mark]

Q3. a). i. List three (3) applications of an accelerometer. [1 mark]

ii. Figure Q3(aI) shows an accelerometer with its frame accelerating with an acceleration of 'a' in the given direction. [0.5 marks]

I. Mark the forces acting on the mass by converting the accelerometer to an inertial frame of reference. [1 mark]

II. Using the Hooke's law, Newton's second law of motion and equilibrium of the mass, derive an expression for acceleration.

[0.5 marks]

iii. Figure Q3(aII) shows a differential capacitor used in an accelerometer. Derive a linear expression for the differential capacitance with respect to Δ. Assume that the cross-sectional area between the plates is "**A**" and permittivity of free space is "ξ" and Δ<<<d. Use the following relationships if necessary.

$(1+x)^{-1} = 1 - x + x^2 - x^3 + \ldots\ldots$ for $x<<<1$

$(1-x)^{-1} = 1 + x + x^2 + x^3 + \ldots\ldots$ for $x<<<1$ [1.5 marks]

iv. Figure Q3(aIII) shows a charge amplifier used inside an accelerometer. If the output voltage, u_{out}, of the charge amplifier is 2 mV, find the charge output, q_{in}, of the acceleration sensor. [1 mark]

b). i. Define orientation and non-inertial frame of reference [1 mark]

ii. Define fictitious force and centripetal force? [1.5 marks]

iii. Let, **xyz** be an inertial frame of reference. An object with mass, **m**, is moving linearly in direction, **y**, with a constant velocity, **v**, and rotating with angular velocity, **ω**, in the direction, **z**, as shown in Figure Q3(bI). Find the magnitude and direction of the Coriolis force acting on this object? [1 mark]

iv. Figure Q3(bII) shows inside of a Micro Electromechanical System (MEMS) gyroscope. Explain with the aid of a marked forces and velocities in Figure Q3(bII), how one (1) dimensional angular velocity can be measured using the MEMS gyroscope. You may define an appropriate inertial frame of reference in your diagram for your explanation. Assume that the unit is rotating anticlockwise as given in Figure Q3(bII). Explanation for only one direction of oscillation of the mass is sufficient. [1.5 marks]

Q4. a) i. State three (3) advantages of a digital sensor compared to an analog sensor. [1 mark]

ii. State what is meant by a communication protocol? [1 mark]

iii. State three (3) communication protocols that are used to communicate with digital sensors.

Note: If you state the protocol in acronym form, you must define what the acronyms stands for. [1 mark]

iv Draw a diagram showing a Master-Slave pair connected with wires for SPI protocol, naming all the wires between the Master and Slave. You must indicate the direction of data flow in each of the wires using an arrow. Briefly explain by referring to the wires, how the Master can write to and read from the Slave.

Note: If you state the wire names as acronyms, you must state what each acronym stands for. [2 marks]

b). i. State the two (2) types of Photon detectors providing an example for each of them. [1 mark]

ii. Write an expression for the Signal to Noise Ratio (SNR) of a photon detector operating in quantum regime. Define all the symbols used in the expression. [1 mark]

iii. A junction photo diode has an internal quantum efficiency, collection efficiency and transmission efficiency 0.9 each. Modulated red color light having an average optical power of 10 nW, optical bandwidth of 1 kHz and wavelength of 700 nm is incident on this diode.

I. Find the responsively and photo current of the photo diode. Assume that the plank's constant as 6.626×10^{-34} J Hz^{-1}, the charge of an electron as 1.602×10^{-19} C and the speed of light as 3×10^{8} ms^{-1}. [1 mark]

II. Find the responsivity and photo current of the photo diode. Assume that the plank's constant as 6.626×10^{-34} J Hz^{-1}, the charge of an electron as 1.602×10^{-19} C and the speed of light as 3×10^{8} ms^{-1}. [0.5 marks]

III. If the photo diode's equivalent electrical circuit is as shown in FigureQ4(b) and the photon detector is in thermal regime; find the Noise Equivalent Power (NEP) of the photo diode. Assume the Boltzmann constant as 1.38×10^{-23} m^2 kg s^{-2} K^{-1} and temperature is 25^0 C. [1.5 marks]

Q5. a). i State three main sources of experimental uncertainties (experimental errors)? . [2 marks]

ii. To determine the quantity $q = x^2y - xy^2$, a scientist measures x and y as follows.

$$x = 3.0 \pm 0.1 , y = 2.0 \pm 0.1$$

Evaluate the answer for q and its uncertainty? [2 marks]

b). Explain the advantages of negative feedback amplifiers. [2 marks]

c). An amplifier without feedback gives fundamental output 36V with 7% second harmonic distortion, when the input is 0.028 V.

i. If 1.2 % of the output is fed back into the input in a negative voltage series feedback, find is the output voltage? [2 marks]

ii. If the fundamental output is maintained at 36 V, but the second harmonic distortion is reduced to 1%, what could be the input voltage? [2 marks]

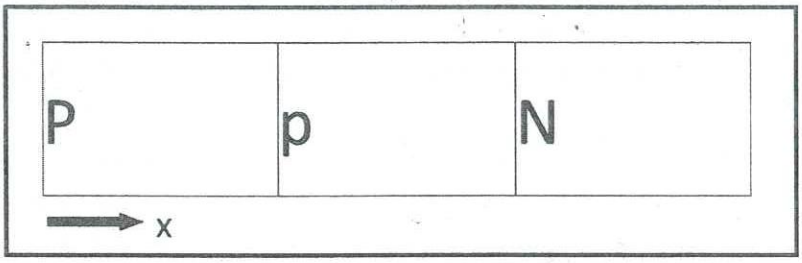

Figure Q1(a): PpN double heterostructure

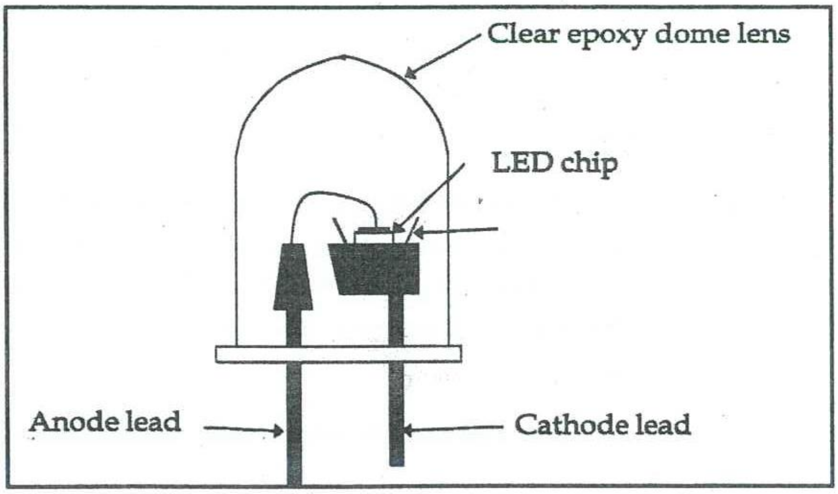

Figure Q1(b): Light Emitting Diode

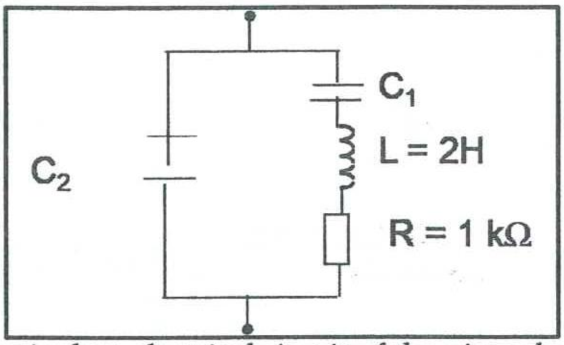

Figure Q2(bI): Equivalent electrical circuit of the piezoelectric transducer

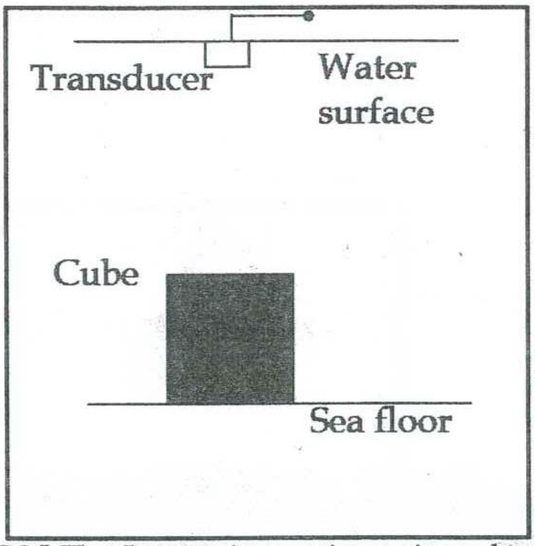

Figure Q2(bII): Immersion testing using a hydrophone

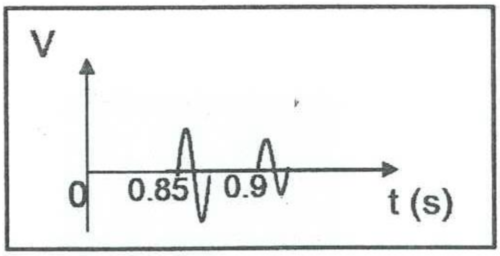

Figure Q2(bIII): Reflected signals shown in the output of the hydrophone.

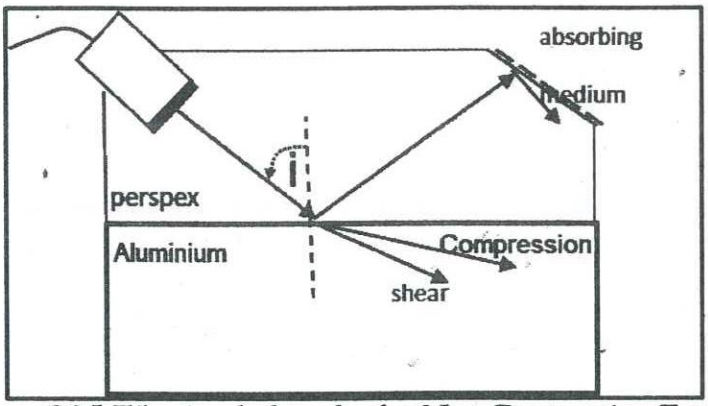

Figure Q2(bIV): Angled probe for Non-Destructive Testing

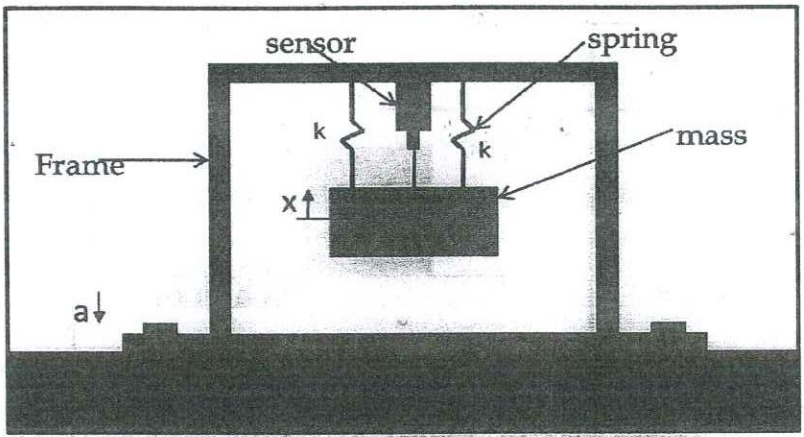

Figure Q3(aI): Undamped accelerometer

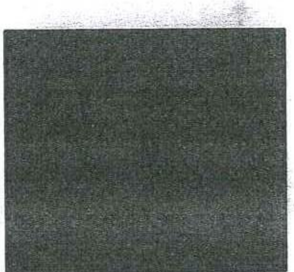
Figure Q3(aII): Differential Capacitor

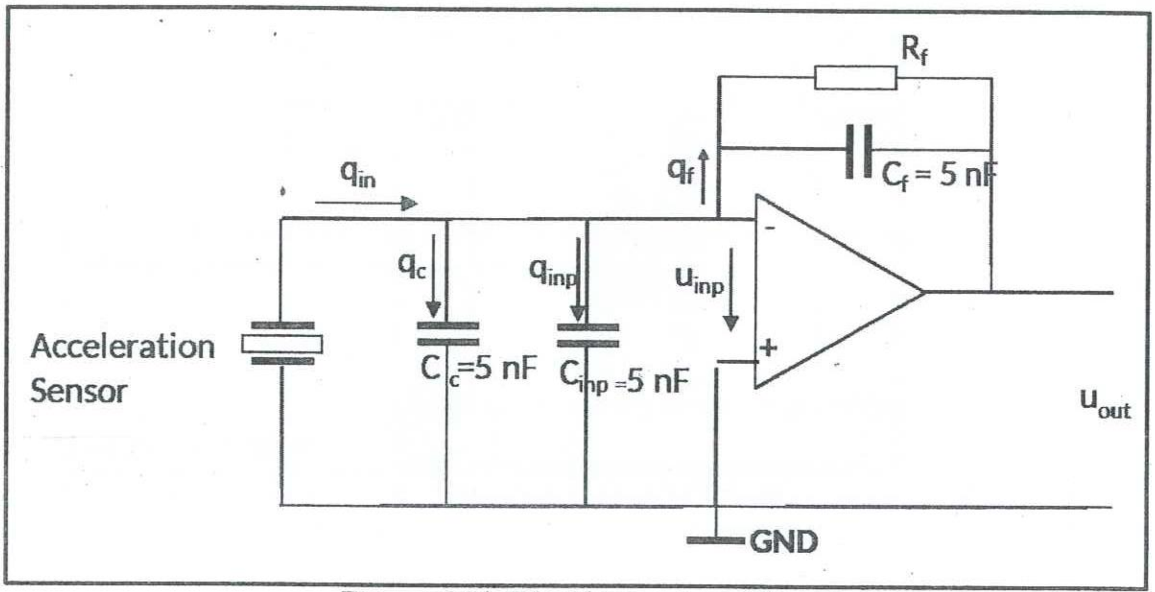

Figure Q3(aIII): Charge Amplifier

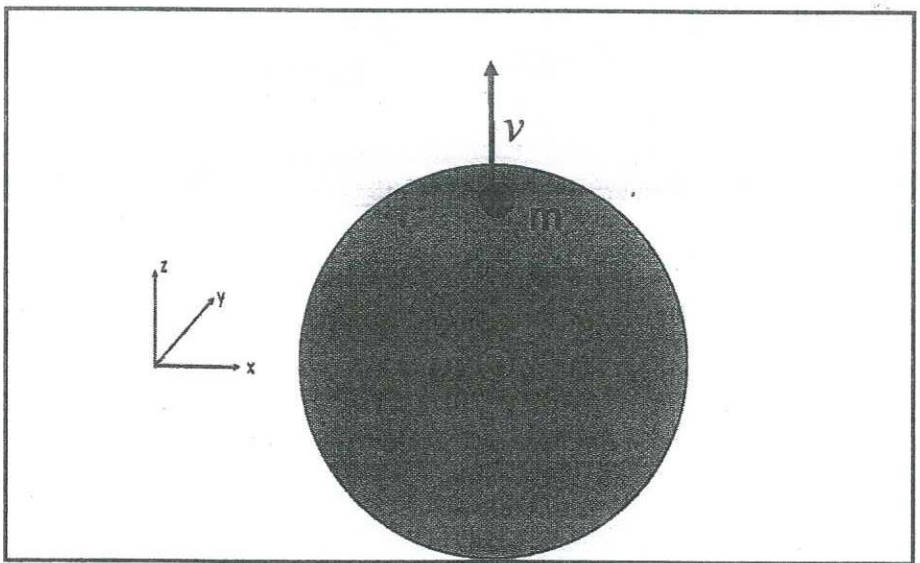

Figure Q3(bI): An object rotating and linearly moving

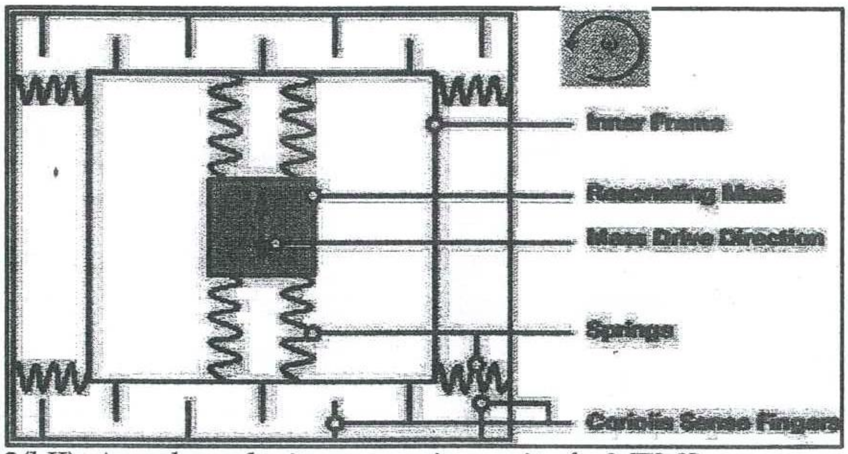

Figure Q3(bII): Angular velocity measuring unit of a MEMS gyroscope

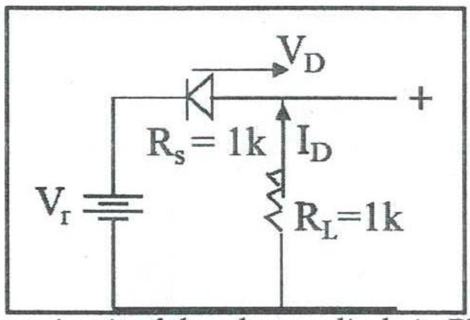

Figure Q4(b): Equivalent circuit of the photon diode in Photo conductive mode