UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2023/2024

COURSE NAME	:	SENSORS AND ACTUATORS
COURSE CODE	:	BND 36103
PROGRAMME CODE	:	BND
EXAMINATION DATE	:	JULY 2024
DURATION	:	3 HOURS
INSTRUCTIONS	:	1. ANSWER **ALL** QUESTIONS 2. THIS FINAL EXAMINATION IS CONDUCTED VIA ☐ Open book ☒ Closed book 3. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

THIS QUESTION PAPER CONSISTS OF **SEVEN (7)** PAGES

Q1 A sensor or actuator can rarely operate on its own. In fact, it is often part of a larger system that may include many sensors, actuators and processing elements.

(a) An outdoor thermometer uses a bimetal strip to sense and display temperature. It is based on the fact that different metals expand at different rates in response to temperature, hence the strip bends at a rate that depends on the temperature. This property is used to move a dial that displays the temperature.

(i) Determine the primary function of the device.

(2 marks)

(ii) Identify whether the device is parametric or self-generating type.

(1 mark)

(iii) Explain the transduction mechanisms that allow the device to function. Explanation should be based on the information given.

(4 marks)

(b) The human ear responds to pressures between $2\ x\ 10^{-5}$ Pa (the threshold for hearing) and 20 Pa (the threshold of pain). Given that $1\ Pa = 1\ {}^{N}/_{m^2}$

(i) Calculate the span of the human ear in dB.

(2 marks)

(ii) A jet engine at a short distance produces a sound pressure of 5000 Pa. An operator must wear hearing protection. Determine the minimum attenuation of the hearing protector in dB.

(2 marks)

(c) A force sensor is used in an electronic scale to weigh items ranging from $1\ gf$ tp $1000\ gf$. The sensor's resistance changes linearly from $1\ M\Omega$ to $1\ k\Omega$ as the force changes from $1\ gf$ to $1000\ gf$ $9.80665\ mN$ to $9.80665\ N$. To measure the resistance, the sensor is connected to a constant current source of 10 μA and the voltage across the sensor is used as the measured quantity. The voltage is measured with a voltmeter with internal impedance of $10\ M\Omega$. The configuration is shown in **Figure Q1 (c)**. Calculate the error produced by the connection of the voltmeter.

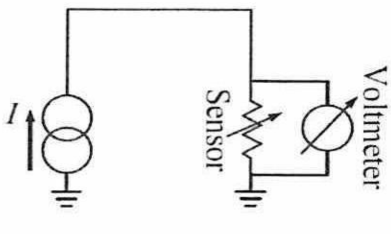

Figure Q1 (c)

(10 marks)

(d) The following is the transfer function of a thermocouple. Derive the sensitivity of the sensor.

$$V = (-2.46 \times 10^{-1}\, T + 5.91 \times 10^{-3}\, T^2 - 1.43 \times 10^{-6}\, T^3 + 2.15 \times 10^{-9}\, T^4 - 3.17 \times 10^{-12}\, T^5 + 2.40 \times 10^{-15}\, T^6 - 9.09 \times 10^{-19}\, T^7 + 1.33 \times 10^{-22}\, T^8) \times 10^{-3} mV$$

(4 marks)

Q2 Optics is the science of light and light is an electromagnetic radiation that manifests itself either as an electromagnetic wave or as photons.

(a) Optical radiation is known to produce quantum effects. State **THREE (3)** effects which classified under the quantum effects.

(3 marks)

(b) The photoconductive sensor depicted in **Figure Q2 (b)** is made of Cadmium sulfide (CdS). Its dimensions are as follows: length of 4 mm, width of 1 mm, and thickness of 0.1 mm. The electron mobility in CdS is around 210 $\frac{cm^2}{Vs}$, while the hole mobility is 20 $\frac{cm^2}{Vs}$. The concentration of carriers in the absence of light, known as the dark concentration, is approximately $10^{16} \frac{carriers}{cm^3}$ for both electrons and holes. At a light density of 1 $\frac{W}{m^2}$ the carrier density increases by 11%:

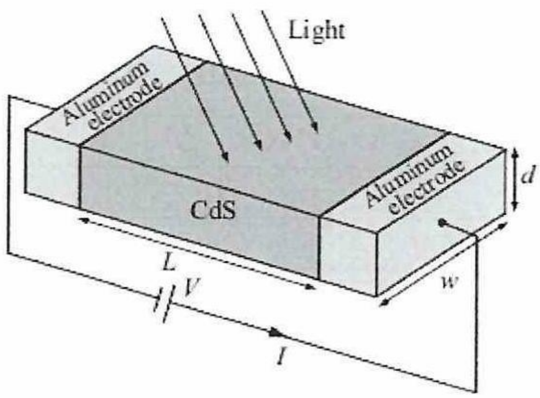

Figure Q2 (b)

(i) Calculate the conductivity of the material and the resistance of the sensor under dark conditions and under the given illumination.

(4 marks)

(ii) Assuming a rate of carrier generation due to light of $10^{15}\ \frac{carriers}{s/cm^3}$, estimate the sensitivity of the sensor to radiation at a wavelength of $300\ nm$.

(7 marks)

(c) An optical sensor is made from a triangular slit cut into opaque material that covers a solar cell to create a triangular area of exposure, as shown in **Figure Q2 (c)**. A moving part is placed above the stationary part and includes two items. One is a stationary source of light, and between the source and the stationary slit is a thin rectangular opening that allows light to go through the opening only. The opening is $t\ m$ wide and the source supplies an illuminance of I lux. The position of the slit is the output of the sensor. Since the larger h (distance) is, the larger the light power on the cell, the larger the voltage of the solar cell. Assuming the voltage output to be linear with the power incident on te solar cell. Assuming the voltage output to be linear with the power incident on the solar cell following the relation $V = kP$, where P is the incident power and k is a constant of the cell. Determine the relation between the measured voltage of the cell and the position of the slit, h.

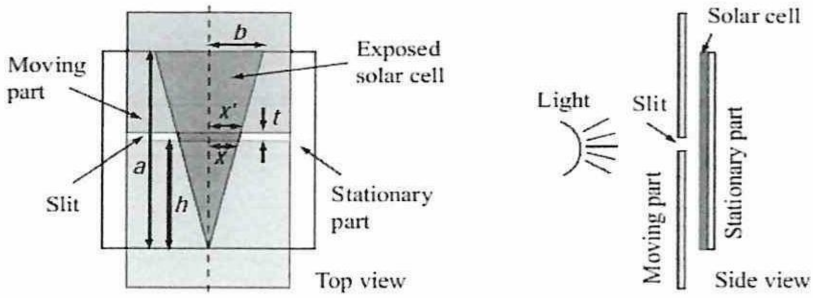

Figure Q2 (c)

(11 marks)

Q3 Magnetic and electric fields are too prevalent and significant to be disregarded.

(a) List **THREE (3)** methods for current and voltage sensing.

(3 marks)

(b) Sketch circuitries to support each of your answer in **Q3 (a)**.

(6 marks)

(c) Explain **THREE (3)** fundamental ways based on methods shown in **Figure Q3 (c)** in which the position and displacement can be used to change the capacitance of a device.

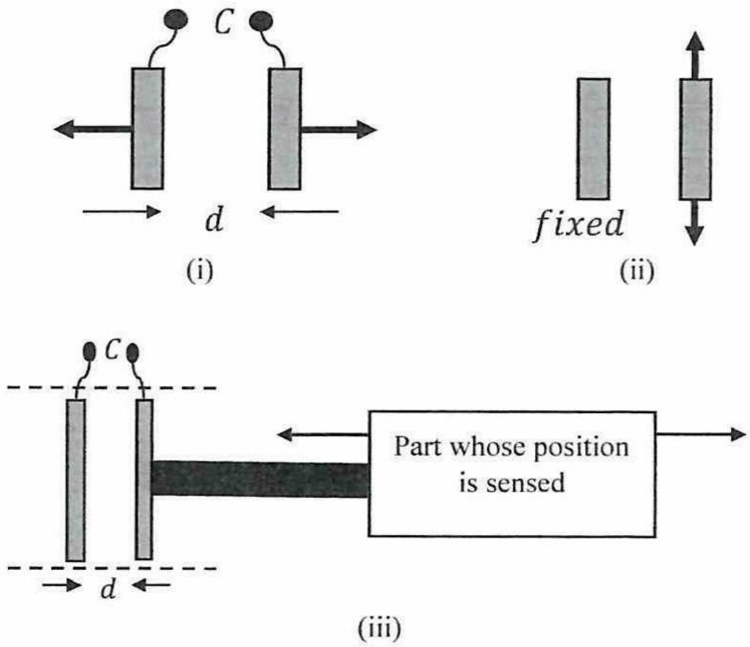

Figure Q3 (c)

(6 marks)

(d) Analyze the capacitance between two parallel plates, as shown in **Figure Q3 (d)**.

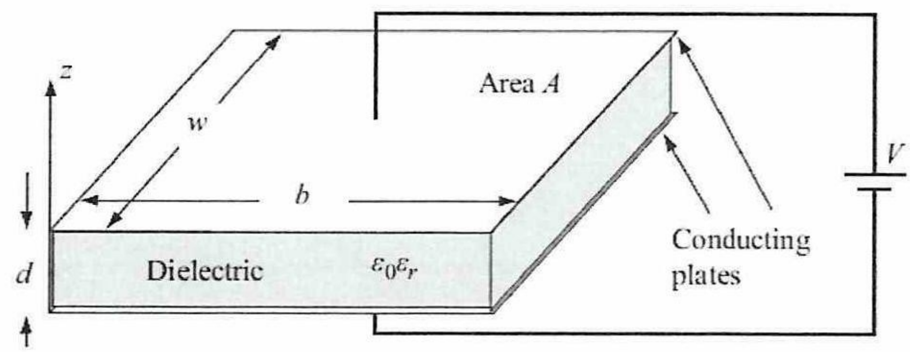

Figure Q3 (d)

(3 marks)

(e) Sandpaper is often produced by attracting the abrasive particles using voltages in excess of $100\ kV$ to the paper after applying a layer of glue, as shown in **Figure Q3 (e)**. The high-voltage supply is applied between the top and bottom surfaces, which are $2\ m$ long, $1.2\ m$ wide, and separated $30\ cm$ apart, forming a capacitor. The abrasive particles are placed on the bottom surface and attracted to the top, sticking to the paper. A small plate of area S is placed at a small distance from the lower conducting surface. The potential difference between the plate and ground is connected to microprocessor to monitor the high voltage across the plate. If the high voltage can carry between $0\ kV$ and $100\ kV$, determine the distance of the small plate from the bottom surface if the microprocessor operates at $5\ V$.

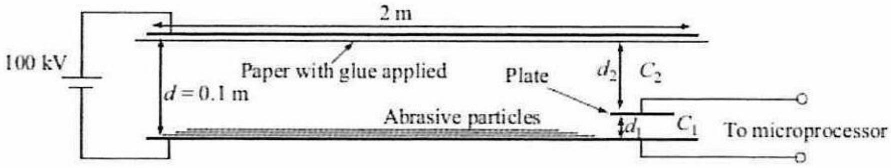

Figure Q3 (e)

(7 marks)

Q4 Although strain gauges measure strain, the strain can be related to stress, force and a host of other stimuli, including displacement, acceleration, or position.

(a) Explain how strain gauge shown in **Figure Q4 (a)** can function as a sensor.

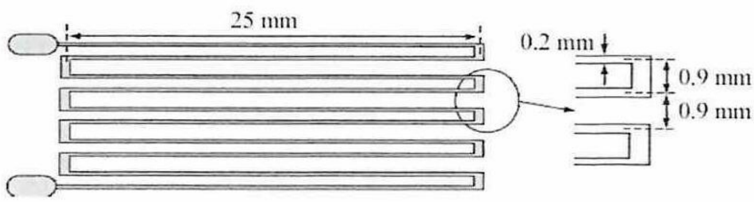

Figure Q4 (a)

(4 marks)

(b) Calculate the resistance of the sensor at 25 °C without strain.

(8 marks)

(c) Calculate the resistance of the sensor if force is applied longitudinally causing a strain of 0.001.

(10 marks)

(d) Estimate the gauge factor from the calculations in **Q4 (a)** and **(b)**.

(3 marks)

- END OF QUESTIONS -

APPENDIX A

Table APPENDIX A.1

Parameter	Formula
Conductivity, [S/m]	$\sigma = e(\mu_n + \mu_p p)$
Resistance, [Ω]	$\frac{L}{\sigma \omega d}$
Sensitivity, [*V/V*]	$G = \frac{V}{L^2}(\mu_n \tau_n + \mu_p \tau_p)$
Change in conductivity, [*S/m*]	$\Delta\sigma = ef(\mu_n \tau_n + \mu_p \tau_p)$ $\Delta\sigma = e(\mu_e \Delta n + \mu_p \Delta p)$
Power, [*W*]	$P = SI$
Output voltage, [*V*]	$V = kP$
Capacitance, [*F*]	$C = \frac{\varepsilon_0 \varepsilon_r S}{d}$
Permittivity of a vacuum, [F/m]	8.854×10^{-12}
Resistance, [Ω]	$R = \frac{L}{\sigma S}$
Gauge resistance, [Ω]	$R_o(1 + \alpha[T - T_o])$
Cross sectional area, [m^2]	$\frac{v_o}{L + \Delta L}$
Section of strain gauge resistance, [Ω]	$\frac{L + \Delta L}{\sigma S'}$
Gauge factor	$\frac{1}{\varepsilon}\frac{dR}{R}$