ENGINEERING TRIPOS PART IIB

Thursday 29 April 2010 2.30 to 4

Module 4C3

ELECTRICAL AND NANO MATERIALS

Answer not more than ***three*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

1 (a) Describe carefully the principles on which (i) pyroelectric and (ii) piezoelectric devices are based, explaining the underlying physics in each case. Explain why ferroelectrics are particularly important in the manufacture of pyroelectric detectors. [50%]

(b) Explain the difference between the passive and active piezoelectric effect and state two practical applications of each. Identify the *mode* of operation of the piezoelectric device in Fig. 1 and derive an expression relating the charge ΔQ generated at the electrode to the applied force F for this device configuration. Define any material parameters you use. [30%]

(c) A PZT-5 ceramic plate of dimensions $0.5 \times 10 \times 10$ mm^3 is used as a piezoelectric microphone based on the arrangement shown in Fig. 1. Calculate the voltage generated between the electrodes when a compressive force of 0.01 N is applied parallel to the direction $\mathbf{x_1}$. Assume $\varepsilon_r = 3400$ and $d_{31} = -274$ pCN^{-1} for PZT-5, and the permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}. [20%]

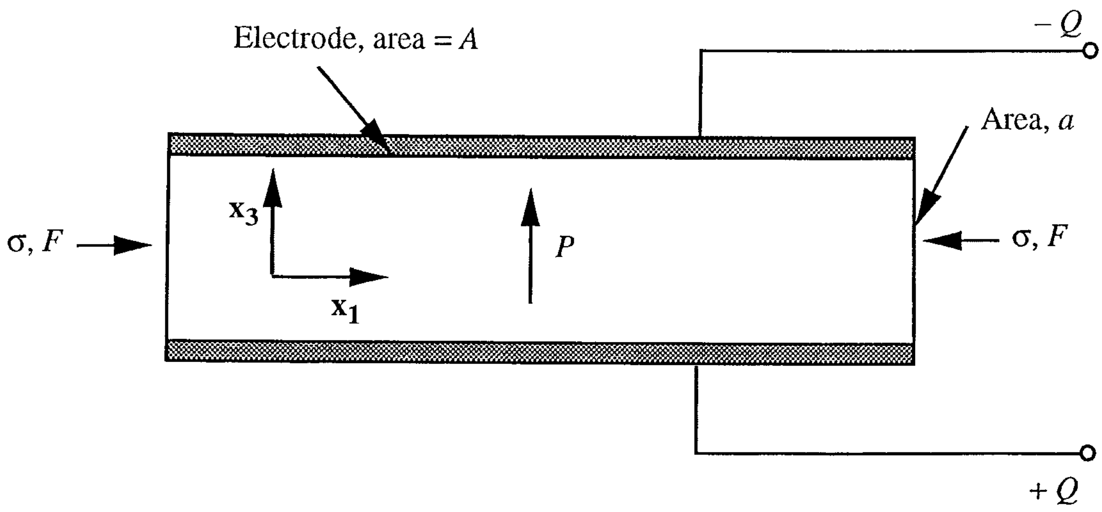

Fig. 1

2 (a) Explain how magnetic field is generated by a type II bulk superconductor, including the role of flux pinning, how this relates to critical current density, J_c, and the distribution of field within the bulk microstructure. You may assume slab geometry for this purpose. [30%]

(b) Sketch the variation of magnetisation with applied magnetic field at constant temperature for (i) an 'ideal' type II superconductor and (ii) a type II superconductor that contains flux pinning centres. Your diagram should show $M(H)$ for a field cycle of 0 T to H_{max} to 0 T, and you should assume that the superconductor is initially unmagnetised in each case. Indicate any important features and parameters on your sketch. [25%]

(c) Show by analogy with a wire-wound solenoid that the flux density at the centre of a long, solid superconducting cylinder carrying a uniform circumferential critical current density throughout its bulk is proportional to the radius of the cylinder. [20%]

(d) A 20 cm long, solid cylinder of Y-Ba-Cu-O (YBCO) has a diameter of 1 cm and carries a uniform circumferential J_c of 5×10^4 Acm^{-2} at 77 K. Stating any assumptions, calculate the flux density at the centre of the cylinder and hence its magnetisation at this temperature. [25%]

(The flux density B at the centre of a long solenoid of N turns, length ℓ and carrying a current I is given by $B = \dfrac{\mu_0 N I}{\ell}$, where μ_0 is the permeability of free space.)

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3 (a) A thermal evaporator is used to deposit aluminium. The evaporator planetary has a radius of 35 cm. A crucible of radius 2 cm, containing the aluminium, is heated to a temperature of 1200 °C, at which the vapour pressure of Al is approximately 1 Pa.

(i) Calculate the deposition rate of aluminium. [15%]

(ii) The evaporation chamber has a background pressure of mainly water vapour, which is assumed to be at room temperature. Determine the background pressure for which the ratio of the rate of arrival of water molecules to aluminium atoms is 0.1. [15%]

(iii) Outline an appropriate pumping scheme for the evacuation of the evaporation chamber, explaining what types of pumps are required and the principle of operation in each case. [20%]

(iv) Discuss why the background pressure decreases when Al evaporates. [10%]

(b) Figure 2 shows two different images taken by a scanning electron microscope of the same array of vertically aligned carbon nanofibres grown on a SiO_2 support.

(i) Explain the difference in contrast based on the principle signals used to form each image. [15%]

(ii) Discuss the origin of the bright spots at the tips of the nanofibres in Fig. 2(b). [10%]

(iii) Describe a suitable non-destructive technique to characterise the chemical composition of the nanofibre tips, stating the principle and the limits of detection. [15%]

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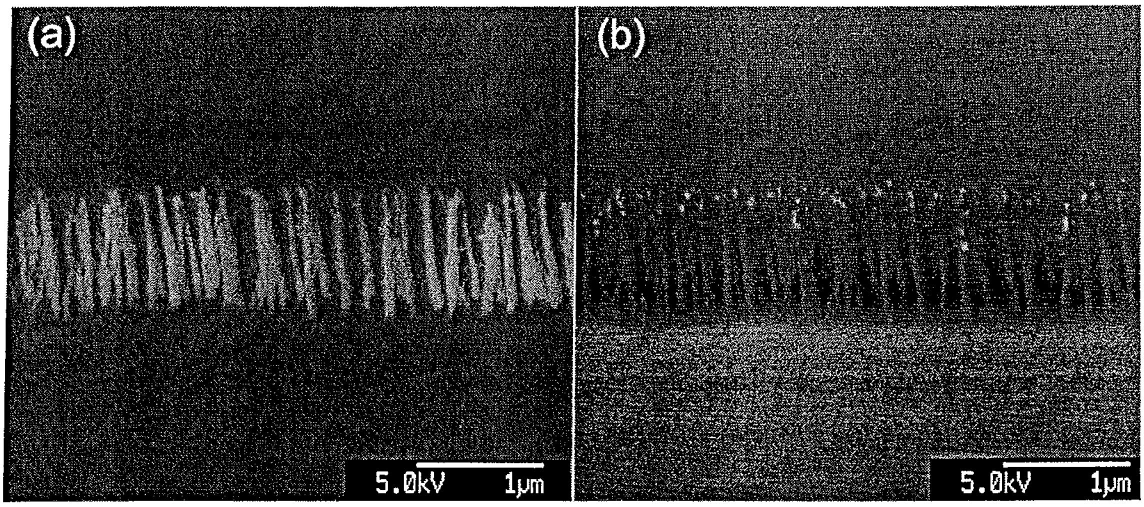

Fig. 2

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4 (a) Explain with a diagram the overall operation of an active matrix liquid crystal display controlled by amorphous silicon thin film transistors. [20%]

(b) Describe carefully the band structure of amorphous silicon, including the nature of states in the different energy ranges, and explain how this is related to the band structure of crystalline silicon. [30%]

(c) Explain the following:

(i) The nature of electronic defects in amorphous silicon;

(ii) The role of hydrogen in amorphous Si:H. [25%]

(d) Describe carefully the structure and operation of a typical thin film transistor based on amorphous silicon. [25%]

5 (a) Describe Moore's law and explain what is meant by transistor scaling. [15%]

(b) Explain how the free surface of a semiconductor can limit the performance of a device. How does the presence of SiO_2 help solve the problem? [10%]

(c) Draw a labelled diagram of a Si-based MOSFET (metal oxide field effect transistor) in an integrated circuit. [15%]

(d) Describe the roles played by SiO_2 in a MOSFET. Which of these roles will be superseded by the use of oxides with high and low dielectric constant, respectively? [20%]

(e) Describe carefully the performance limitations of the components of a MOSFET, other than SiO_2, associated with the materials used currently to manufacture these devices. Give examples of how a new material will improve MOSFET performance in each case. [40%]

END OF PAPER