ENGINEERING TRIPOS PART IIB
ELECTRICAL AND INFORMATION SCIENCES TRIPOS PART II

Monday 28 April 2003 2.30 to 4.00

Module 4C3

ELECTRICAL 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.*

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 Inviliator

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Version 2

1 (a) Sketch the variation of magnetisation with applied magnetic field at constant temperature over a full field cycle for:

(i) a hard permanent magnet material and

(ii) a type II superconductor which contains magnetic flux pinning centres.

In each case, assume the material to be in an initially unmagnetised state. Indicate the key features on each sketch and describe briefly the physical factors that determine their magnitude. [50%]

(b) Nickel has a FCC crystal structure with lattice parameter of 0.55 nm and 0.6 unpaired spins per atom. Calculate the saturation magnetisation and corresponding saturation magnetic flux density of nickel. [25%]

(c) A magnetised YBCO disc of diameter 4.4 cm traps an average magnetic flux density of 5T. Calculate the minimum wall thickness of a reinforcing mild steel band required to resist the magnetic pressure associated with this field. You may assume that the wall thickness of the reinforcing band is small compared to its radius, and that none of the stress is borne by the superconductor. [25%]

$\mu_B = 9.27 \times 10^{-24}$ Am^2

2 (a) Explain the classification of pyroelectric and piezoelectric materials in terms of the polar properties of their crystallographic lattice. Hence, describe the pyroelectric and piezoelectric effects that are observed in some dielectric materials, explaining the microscopic basis of their occurrence. [40%]

(b) Write down the piezoelectric equations of state, defining all the terms that you use. Show that these reduce to Hooke's law and $P = \chi\varepsilon_0 E$ in the appropriate limit. [20%]

(c) A piezoelectric microphone consists of a poled PZT-5 ferroelectric rod of square section with dimensions 1 mm × 1 mm × 5 mm operating in longitudinal mode, as shown in fig. 1. From the appropriate equation in (b), show that the charge generated by this configuration is proportional to the aspect ratio of the device area, A/a. [20%]

Calculate the charge Q generated by the microphone if the PZT-5 rod is subjected to an instantaneous force of 1 N applied perpendicular to area a. [20%]

$d_{31} = 274$ pC N^{-1} for PZT–5.

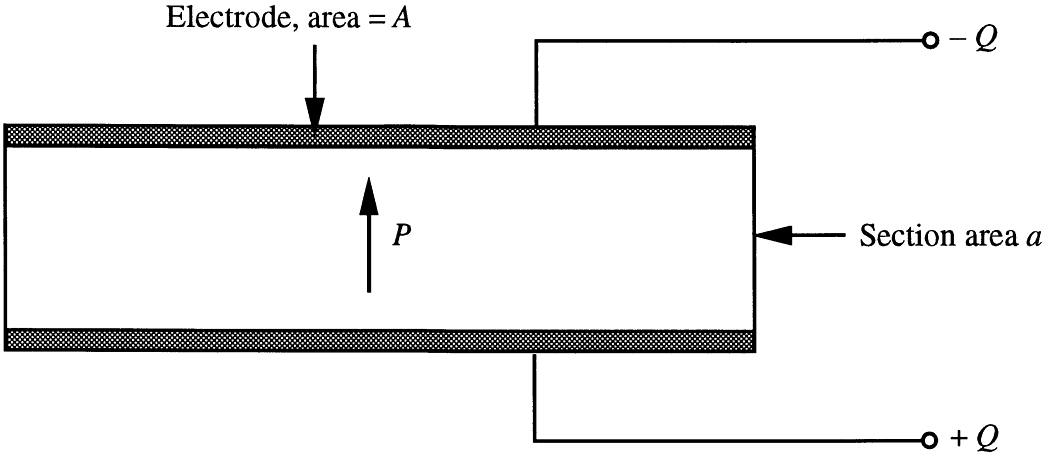

Fig. 1

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3 (a) (i) Describe the principles of X-ray and electron diffraction.

(ii) Derive the Bragg expression for the angle of diffracted X-ray intensity, explaining the meaning of each term;

$$n\lambda = 2d\sin\theta$$

[30%]

(b) Explain how diffraction can be used to analyse materials and to monitor thin films during deposition. Make clear the advantages and disadvantages of the technique, and the range of elements it can measure. [20%]

(c) (i) Describe the EDAX system of analysis as used in the scanning electron microscope.

(ii) Explain what limits the spatial resolution of the EDAX technique and the range of elements that can be detected.

(iii) Why are voltages of the order of kV required for EDAX and why do electrons with such energies do relatively little damage to the sample? [30%]

(d) Describe briefly one other technique for analysing the composition or structure of electrical materials and compare this with the techniques in (a) and (c). [20%]

4 (a) Sketch the E-k curves for direct gap and indirect gap semiconductors and give one example of each type of semiconductor in each case. Explain why a direct band gap is required for an opto-electronic semiconductor. [20%]

(b) Describe how the confinement of electrons and holes is arranged in light-emitting semiconductor structures. Explain the problems this causes with the growth of these structures. [40%]

(c) Why is it difficult to find pairs of semiconductors that can be used together in light-emitting semiconductor structures? [40%]

5 (a) Identify by group the elements that should be used to dope group IV, III-V and II-VI n-type and p-type semiconductors. Give one example of a suitable dopant in each case. [30%]

(b) Which elements can be used for interstitial doping? Identify one limitation associated with the use of interstitial dopants. [10%]

(c) Describe the processes that limit doping efficiency in semiconductors. Which of these processes limits doping in wide band gap semiconductors, and why? [30%]

(d) Identify the sources of trapped charge in silicon dioxide. As a result, explain why interstitial dopants are not used for silicon devices. [30%]

END OF PAPER