UNIVERSITY OF CAMBRIDGE

ENGINEERING TRIPOS PART IIB

Monday 26 April 2004 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 to this paper.

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

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1 (a) Describe the effects of:

(i) surface;

(ii) shape

on the magnetic properties of permanent magnet materials. Explain the significance of these effects for hard and soft magnetic materials, using diagrams to illustrate your answer. [40%]

(b) The demagnetising field, $\boldsymbol{H}_{\mathbf{m}}$, of a magnetic material is related to the applied field, $\boldsymbol{H}_{\mathbf{0}}$, and the magnetisation, $\boldsymbol{M}$, by $\boldsymbol{H}_{\mathbf{m}} = \boldsymbol{H}_{\mathbf{0}} - N\boldsymbol{M}$, where N is the shape-related demagnetising factor. Show that the flux density, $\boldsymbol{B}_{\mathbf{m}}$, in a magnetic material with demagnetising factor N in the absence of an applied field is given by

$$\boldsymbol{B}_{\mathbf{m}} = \mu_0 \boldsymbol{H}_{\mathbf{m}} \left(\frac{N-1}{N} \right).$$

Calculate approximate values of B, H and M in a fully magnetised sphere of Alcomax III. [30%]

(c) How does the magnetic flux density of the fully magnetised Alcomax III sphere in (b) compare with that at the centre of a long superconducting cylinder of YBCO of wall thickness 1 mm, carrying a uniform circumferential current density of 5×10^3 Acm^{-2} at 77 K? Outline the practical difficulties in using the field generated by such a superconductor. [30%]

2 (a) Describe the pyroelectric effect that is observed in some dielectric materials and explain the microscopic basis of its occurrence. Explain carefully why ferroelectrics are important in the manufacture of pyroelectric detectors. [40%]

(b) The voltage responsivity of a pyroelectric detector is given by the following equation

$$R_V = \frac{R_G \eta p A \omega}{G_T \sqrt{1 + \omega^2 \tau_T^2} \sqrt{1 + \omega^2 \tau_E^2}} .$$

Explain carefully the meaning of each term and illustrate graphically the significance of τ_T and τ_E. Draw an electrical circuit suitable for reading-out the voltage response of a pyroelectric detector and label the circuit components. [30%]

(c) Assuming that the element capacitance is large compared to the amplifier capacitance, rank the ferroelectric materials listed in Table 1 in order of potential for use in a pyroelectric detector that exhibits the following properties:

(i) A high voltage response;
(ii) A high signal to noise ratio.

Explain any equations you use. The permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}. [30%]

Material	T_c °C	p $\mu Cm^{-2}K^{-1}$	ε_r	$\tan \delta$ $\times 10^{-3}$	c $MJm^{-3}K^{-1}$
PZFNTU	230	380	290	10	2.5
SBN - 50	121	550	400	3	2.3
PVDF	80	27	12	15	2.6
PGO	178	110	40	0.5	2.0

Table 1

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3 (a) Derive expressions for the following:

(i) The mean free path of a molecule in a gas;
(ii) The time taken to form a monolayer on a substrate assuming all the impinging atoms stick.

Express your answers in terms of the molecular diameter, d , the number of molecules per m^3, n and the molecular velocity, v . Assume that at any instant one sixth of the molecules are travelling in a particular direction. [30%]

(b) Describe the problems encountered in achieving a high vacuum and the precautions taken to avoid them. [20%]

(c) List as many techniques as you can for the deposition of thin films.

Describe two of these techniques in detail, comparing the materials they can be used for, the deposition rate and other characteristics of the deposition process. [50%]

4 (a) (i) State Moore's law.
(ii) The typical feature size of a particular Si device in 2003 was 0.13 μm. Estimate its size in 1975. [30%]

(b) Sketch a typical n-type MOS (NMOS) FET with electrodes. Name the materials used currently for each part of the device. Which equivalent materials were used for the conducting components of an early NMOS transistor in 1970?

Explain briefly why the materials used in 1970 evolved into those used today. [40%]

(c) State three roles of silicon dioxide in a planar FET. [10%]

(d) Explain electromigration. What significant change in species of metal was introduced recently in response to this effect? [20%]

5 (a) Derive Young's equation for the contact angle for wetting of two condensed phases. [40%]

(b) State carefully the limiting cases of contact angle for wetting and non-wetting. [20%]

(c) Explain how Young's equation describes the shape of a new condensed phase B as it grows (nucleates) on a flat surface of an existing condensed phase A. Hence give the condition for 3-dimensional (non-island) growth. [20%]

(d) Derive the reverse condition for the growth of condensed phase A on the surface of condensed phase B. What may be concluded by comparing this with the results of (c). [20%]

END OF PAPER