Version SH/4

EGT3
ENGINEERING TRIPOS PART IIB

Friday 24 April 2015 9.30 to 11

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.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper.

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

1 (a) The Bean model can be used to relate the current flow in a superconductor to its magnetisation. Explain how the slab of superconducting material in Fig. 1 can be fully magnetised through the application of a magnetic field, ***B***, parallel to the slab. State all assumptions used. Use cross sectional diagrams of the current and field inside the slab to illustrate your answer. [30%]

(b) (i) Use the Maxwell equation $\mathrm{curl}\,\boldsymbol{H} = \boldsymbol{J} + \frac{d\boldsymbol{D}}{dt}$ to derive an equation that relates the local variation of magnetic field, ***B***, to distance *x* across the slab shown in Fig. 1. Assume that the local magnetic dipoles in the material can be neglected (i.e. that $\boldsymbol{B} = \mu_0\boldsymbol{H}$). [25%]

(ii) Use your answer from part (i) to write an equation that relates the magnetisation of a superconductor shaped as shown in Fig. 1 to its critical current density. How can this relationship be used to enable the measurement of the critical current density of a superconductor? [15%]

(c) For a slab of material as shown in Fig. 1 calculate the magnetisation for both d = 4 mm and d = 8 mm for the cases where:

(i) the slab is made out of magnetised NdFeB with a remnant field of 1 T. [15%]

(ii) the slab is made out of a superconductor which exhibits a critical current density of $8\text{x}10^8$ A/m^2. [15%]

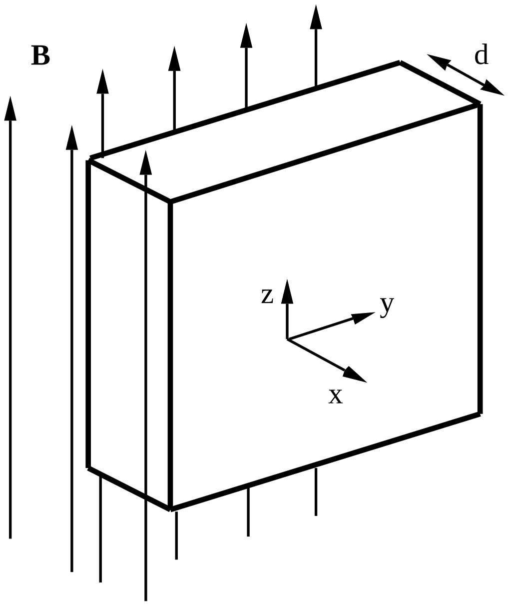

Fig. 1

2 (a) Define a pyroelectric material. Explain how the pyroelectric effect arises in some ceramic materials in terms of the symmetry and arrangement of the crystal lattice. [20%]

(b) Explain why, in practice, ferroelectric materials are used in pyroelectric devices. Which additional property of ferroelectrics must be considered when choosing a ferroelectric material for pyroelectric applications? [15%]

(c) Describe the operation of a pyroelectric detector, such as that used in motion detector devices. Include an outline circuit diagram in your answer. State three fundamental requirements of the pyroelectric element for a good response to infra-red radiation. State briefly the conditions under which the detector will operate under (i) current and (ii) voltage mode. [30%]

(d) The temperature difference ΔT between a pyroelectric element and its surroundings when exposed to sinusoidally modulated, incident radiation $W(t) = W_0 e^{i\omega t}$ is described by

$$\Delta T = \frac{\eta W_0 e^{i\omega t}}{G_T + i\omega H}$$

where η is the emissivity of the absorbing electrode, G_T is the thermal conductance to the surroundings and H is the heat capacity.

(i) Define the voltage responsivity R_V of the detector, and hence derive the following expression

$$R_V = \frac{R_G \eta\, pA\omega}{G_T \sqrt{1+\omega^2\tau_T^2}\sqrt{1+\omega^2\tau_E^2}}$$

where R_G is the gate resistance, p is the pyroelectric coefficient, A is the area of the absorbing electrode, τ_T is the thermal time constant and τ_E is the electrical time constant. [25%]

(ii) R_V is maximised for the case where $\omega = (\tau_E \tau_T)^{-0.5}$. Write an equation for R_V in this case. How can a pyroelectric imaging system be designed, for a given pyroelectric material and readout circuit, to ensure that it operates with maximum voltage responsivity. [10%]

3 (a) A thermal evaporator is used to deposit aluminium on a patterned Si wafer.

(i) Outline the basic principle of evaporation and explain why a low background pressure is desirable. [15%]

(ii) Explain why the background pressure decreases when Al starts to evaporate. [10%]

(iii) Estimate the mean free path of evaporated Al atoms assuming a background pressure of 10^{-7} mbar consisting of mainly water vapour at room temperature. State all your assumptions. Explain why a poor step coverage can be expected. [20%]

(iv) Describe two methods to improve the step coverage of the Al evaporation. [10%]

(b) A graphene layer is transferred onto a planar oxidised Si wafer. Outline a suitable characterisation technique to show each of the following properties, in each case describing the principle of detection:

(i) the graphene is only one monolayer thick; [15%]

(ii) the graphene only consists of carbon atoms. [15%]

(c) Al is evaporated onto the graphene layer. It is found that the Al forms discrete small islands rather than a continuous thin film. Discuss why. [15%]

4 (a) Explain the difference between volatile and non-volatile memories. [15%]

(b) Draw a labelled diagram of a Flash memory transistor. [20%]

(c) Using Gauss’ law or otherwise, explain how stored charge can alter the gate turn-on voltage of a Flash memory transistor. [30%]

(d) Describe the various conduction processes in insulators, and thus describe the processes used for charge and discharge in a Flash memory. [20%]

(e) Explain how you might scale a Flash memory to higher memory densities, in terms of for example materials, device structures and dimensions. [15%]

5 (a) Describe three different contemporary display technologies and their basic operating mechanisms. [25%]

(b) Draw a labelled schematic of an amorphous Si thin film transistor, explaining the role of each part. [20%]

(c) Explain what is meant by defect passivation and its importance, and thus how SiO_2 passivates the Si surface. [15%]

(d) By analogy to the network of SiO_2, draw the network of the insulator silicon nitride, Si_3N_4. [15%]

(e) Following the analogy in part (d), explain how a Si_3N_4 gate dielectric can passivate an amorphous Si surface. [15%]

(f) Give options for increasing the drain current of an amorphous thin film based transistor. [10%]

END OF PAPER

Numerical answers:

Q1 (c) ~796 kA/m, 0.8MA/m, 1.6 MA/m; Q3 (a)(iii) $\lambda_{mfp} \approx 0.5$ km