ENGINEERING TRIPOS PART IIB

Monday 07 May 2012 9 to 10.30

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.

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
Single-sided script paper	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

DAC04

1 (a) Describe the Bean model of current flow in type II bulk superconductors. Explain carefully how the thin superconducting slab shown in Fig. 1 can be fully magnetized via the application of a magnetic field $\boldsymbol{B}$ parallel to the slab surface from an initially unmagnetised state after cooling to the superconducting state. Use diagrams of the cross section of the slab to support your answer. [30%]

(b) (i) Derive an equation for the variation of the field gradient $\frac{\mathrm{d}\boldsymbol{B}}{\mathrm{d}x}$ with critical current density $\boldsymbol{J_c}$ for the type II superconducting slab of thickness d shown in Fig. 1. State any assumptions you make. [25%]

(ii) Sketch the field and current distribution through the cross section of the slab for an applied field that just penetrates to the centre of the slab if $\boldsymbol{J_c}$ varies inversely with $\boldsymbol{B}$. [15%]

(c) Using the equation derived in part (b), calculate the maximum trapped field by a superconducting slab of thickness 1 cm that carries a uniform critical current density of 5×10^4 A cm^{-2}. How does this compare with the maximum field produced by a long iron cylinder magnetized along its length? Comment on the difference in energy density. [30%]

(cont.

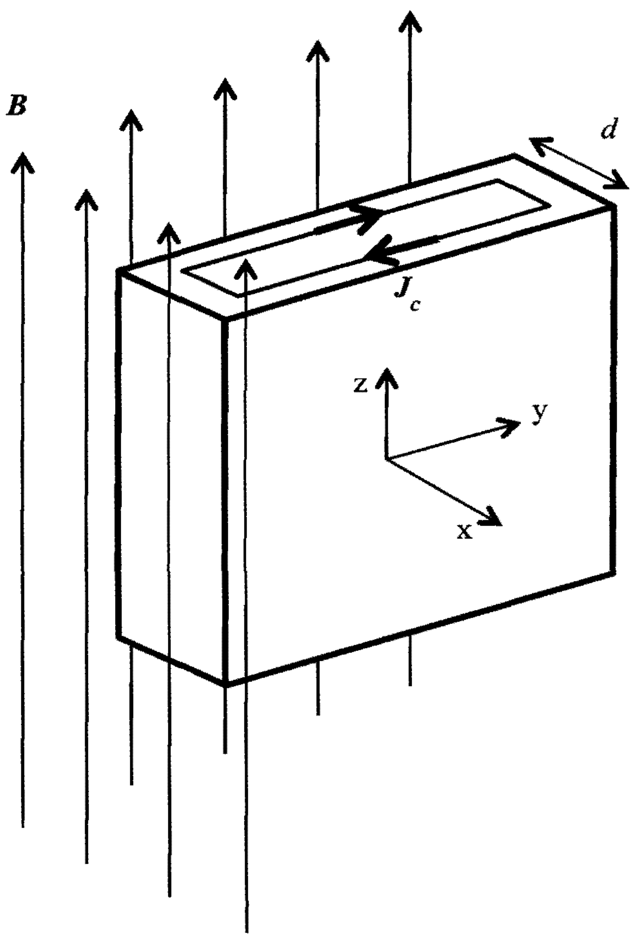

Fig. 1

(TURN OVER

2 (a) Describe how materials are classified as pyroelectric. Explain carefully why ferroelectrics are particularly useful for the manufacture of practical pyroelectric devices. [25%]

(b) Describe the operation of a pyroelectric detector, such as that used in PIR devices, and include a typical circuit diagram in your answer. State three fundamental requirements of a 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 responsivity. [30%]

(c) The temperature difference ΔT between a pyroelectric element and its surroundings when exposed to sinusoidally modulated, incident radiation $W = W_0 \, e^{i\omega t}$ is given 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 thermal capacity. Define the voltage responsivity R_V of the detector, and hence derive the following expression

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

where the symbols have their usual meaning. [25%]

(d) A pyroelectric material that exhibits a high signal to noise ratio is to be selected from those listed in Table 1. Derive an appropriate rank order list of performance of these materials, explaining briefly the origin of any equations you use. [20%]

The permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}.

(cont.

Material	T_c °C	p μC m^{-2} K^{-1}	ε_r	tan δ	c MJ m^{-3} K^{-1}
PZFNTU	230	380	290	10.0×10^{-3}	2.5
SBN - 50	121	550	400	3.0×10^{-3}	2.3
PVDF	80	27	12	15.0×10^{-3}	2.6
PGO	178	110	40	0.5×10^{-3}	2.0

Table 1

(TURN OVER

3 (a) Figure 2 shows schematically the processes involved in the chemical vapour deposition (CVD) of a thin film. Describe the steps labelled 1-7. [15%]

(b) The mass transfer coefficient for the CVD deposition of an amorphous silicon film is found to be $h_g = 10$ cm s^{-1}. The surface reaction rate coefficient for this process is given by $k_s = 10^7 \times \exp(-E_a/kT)$ cm s^{-1}, where $E_a = 1.9$ eV. Two common CVD reactor arrangements are (i) a cold-walled, graphite susceptor type, and (ii) a hot-walled, stacked wafer type. Which of these types of reactor arrangement you would recommend for the deposition of an amorphous silicon film at a deposition temperature of 900 °C? Give reasons to explain your answer. [20%]

(c) Oxidation of an amorphous silicon film surface is minimised by either a high vacuum or a protective gas atmosphere, such as Ar. Given that a typical turbo-molecular pump allows a vacuum of 10^{-6} mbar, estimate the purity of Ar, in atomic percent oxygen, that would produce the same oxidation rate if the Ar were at atmospheric pressure. [20%]

(d) Outline one characterisation technique to measure the film thickness of a uniform, amorphous silicon film deposited onto an oxidised silicon wafer. [10%]

(e) X-ray photoelectron spectroscopy (XPS) is used to characterise an amorphous silicon film.

(i) Describe the principles of XPS and the materials properties it can measure. Estimate the typical detection range, in terms of atomic concentration, and indicate whether this is sufficient to resolve doping concentrations used in silicon technology. [20%]

(ii) A synchrotron is used as an X-ray source for XPS. Explain how the tunability of the X-ray energy can be used to perform depth-resolved XPS using this X-ray source. State the order of magnitude of depth to which typical XPS information may be obtained. [15%]

(cont.

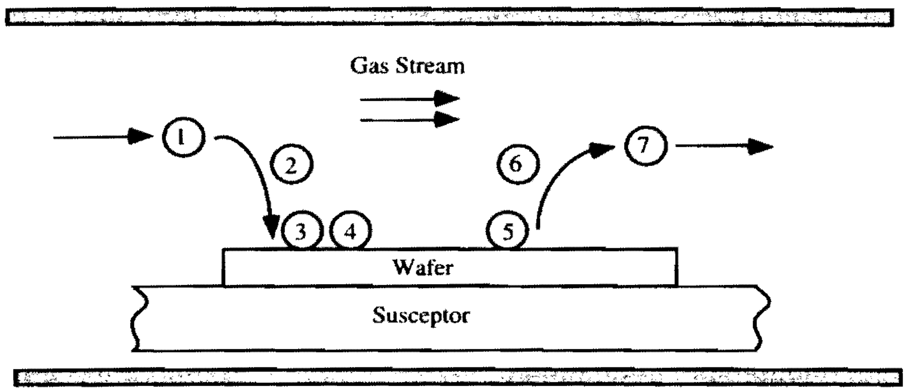

Fig. 2

(TURN OVER

4 (a) Draw a labelled diagram of an active matrix liquid crystal display element, controlled by amorphous silicon thin film transistors. Explain briefly the mode of operation of this device. [20%]

(b) Draw a separate diagram of the cross-section of the thin film transistor that controls a pixel element of the active matrix liquid crystal display in part (a). Identify the various materials used in this transistor, and explain its operation with reference to that of a conventional MOS transistor. [25%]

(c) Describe the nature of the states in amorphous silicon (a-Si) in the different energy ranges in terms of their origin and conduction properties. Explain how these states are related to the band structure of crystalline silicon. [25%]

(d) Explain the nature of electronic defects in amorphous silicon and the role of hydrogen in amorphous Si:H. [20%]

(e) Explain how a mesh of carbon nanotubes could also be used as a thin film transistor, outlining briefly how the properties of the nanotubes can be controlled for this application. [10%]

5 (a) Draw a labelled diagram showing the main components of a modern metal oxide field effect transistor. Identify the materials required for the various components of this device. [20%]

(b) Explain how the materials have changed for the following components, giving the reasons in each case:

(i) interconnects;
(ii) gate oxide;
(iii) channel;
(iv) interconnect dielectric. [20%]

(c) (i) Draw a schematic diagram of a semiconductor band structure that includes defect states. Explain the origin of these states in terms of simple bonding models. [20%]

(ii) Explain why defects are undesirable in semiconductors, and outline the various causes of defects in the bulk and at the surface of semiconductor materials. [20%]

(d) Explain what is meant by defect passivation. What elements are effective passivants for point defects? How are semiconductor surfaces passivated in a planar semiconductor device, and how does this remove defect states from the band structure? [20%]

END OF PAPER