ENGINEERING TRIPOS PART IB

Friday 7 June 2002 2 to 4

Paper 8

SELECTED TOPICS

*Answer not more than **four** questions.*

*Answer questions from **two** sections only.*

*Do not answer more than **two** questions from any section.*

All questions carry the same number of marks.

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

The answers to questions in each section should be tied together and handed in separately.

Section A (Civil and Structural Engineering) 2
Section B (Mechanical Engineering, Manufacture and Management) 7
Section C (Aerothermal Engineering) 10
Section D (Electrical Engineering) 13
Section E (Information Engineering) 16

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

(TURN OVER

SECTION A (Civil and Structural Engineering)
Do not answer more than **two** *questions from this section*

1 A smooth vertical sheet pile wall is driven into dry sand to support the proposed excavation of depth h shown in Fig. 1. The wall is driven to a penetration depth d below the proposed excavation level and is propped at the top before the excavation is undertaken.

(a) By considering the active and passive pressure distributions acting on the wall, and assuming that the unit weight of the sand is constant with depth, show that the critical value of d at which the wall is just prevented from rotational failure about the prop is independent of the unit weight of the sand and is given by the following equation:

$$\frac{(h+d)^3}{d^2\left(h+\frac{2}{3}d\right)} = \frac{3K_P}{2K_A}$$

where K_A is the coefficient of active earth pressure and K_P is the coefficient of passive earth pressure. [5]

(b) Using trial and error and assuming that the critical state angle of friction for the sand is 30 degrees, estimate the penetration depth d (to the nearest 0.5m) at which the wall would just be stable for an excavation depth h of 8m. [5]

(c) A penetration depth d of 6m is chosen by the designer for an excavation depth h of 8m and the 14m long wall is driven into place and propped at the top. After the excavation has been undertaken to a depth of 8m a uniform surcharge pressure of 20 kN/m^2 is applied to the ground surface behind the wall. Assuming that the unit weight of the sand is 20 kN/m^3 and taking the factor of safety against rotational failure to be defined as the ratio of the maximum possible passive resisting moment to the maximum possible active moment, what is the factor of safety? [10]

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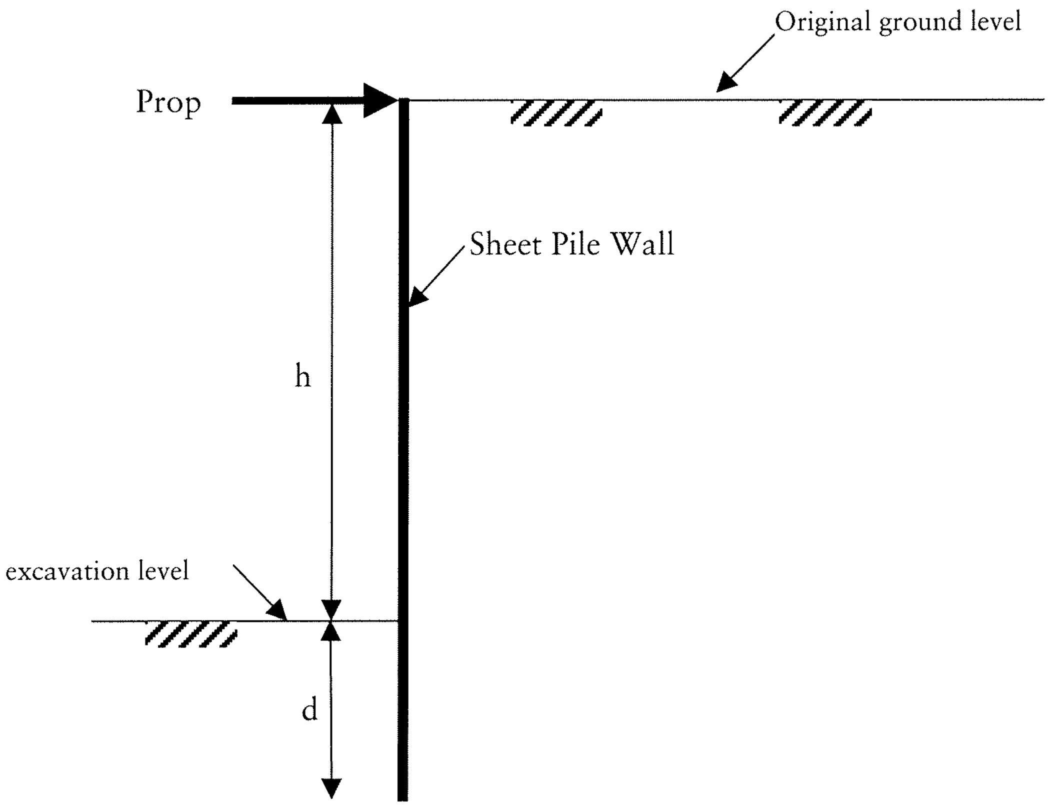

Fig. 1

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2 You have been asked to report on the feasibility of constructing a new sewer tunnel beneath an historic city with many old buildings. The client has determined that the diameter of the tunnel is to be 4m. Advice is needed from you on the optimum depth for the tunnel. The typical ground profile for the city is 5m of gravel fill, underlain by 15m of soft clay, 5m of highly permeable sandy gravel, and then a considerable depth of stiff clay, as shown in Fig. 2. A major river runs through the city, and the area in question is in the flood plain of the river; the water table is almost at the ground surface.

The unit weight of the fill above and below the water table is approximately 18 kN/m^3. The unit weight of the soft clay is 17 kN/m^3 and its average undrained shear strength is 25 kN/m^2. The unit weight of the sandy gravel and the stiff clay layers is 20 kN/m^3. The average undrained strength of the stiff clay is 175 kN/m^2.

(a) Advise the client on the potential problems of constructing the tunnel with its centreline at the following alternative depths:

(i) 12.5 m
(ii) 35 m

Illustrate your answer by considering the stability ratio for these cases and comment on its significance. What methods of tunnel construction would be appropriate in each case? [8]

(b) What is the principal problem with constructing the tunnel if its centerline was at a depth of 25m? Describe two alternative techniques of dealing with this problem. [6]

(c) Most of the buildings are of masonry construction on shallow footings founded in the fill, and many are of considerable historic importance. In the case of the tunnel being constructed at a depth of 12.5m the predicted magnitudes of settlement indicate that some buildings may experience unacceptable damage. What are the principal factors concerning the shape of the predicted settlement trough and the position of the building that determine whether damage is likely? Suggest two possible options for protective measures for this project, giving brief descriptions of the principal features. [6]

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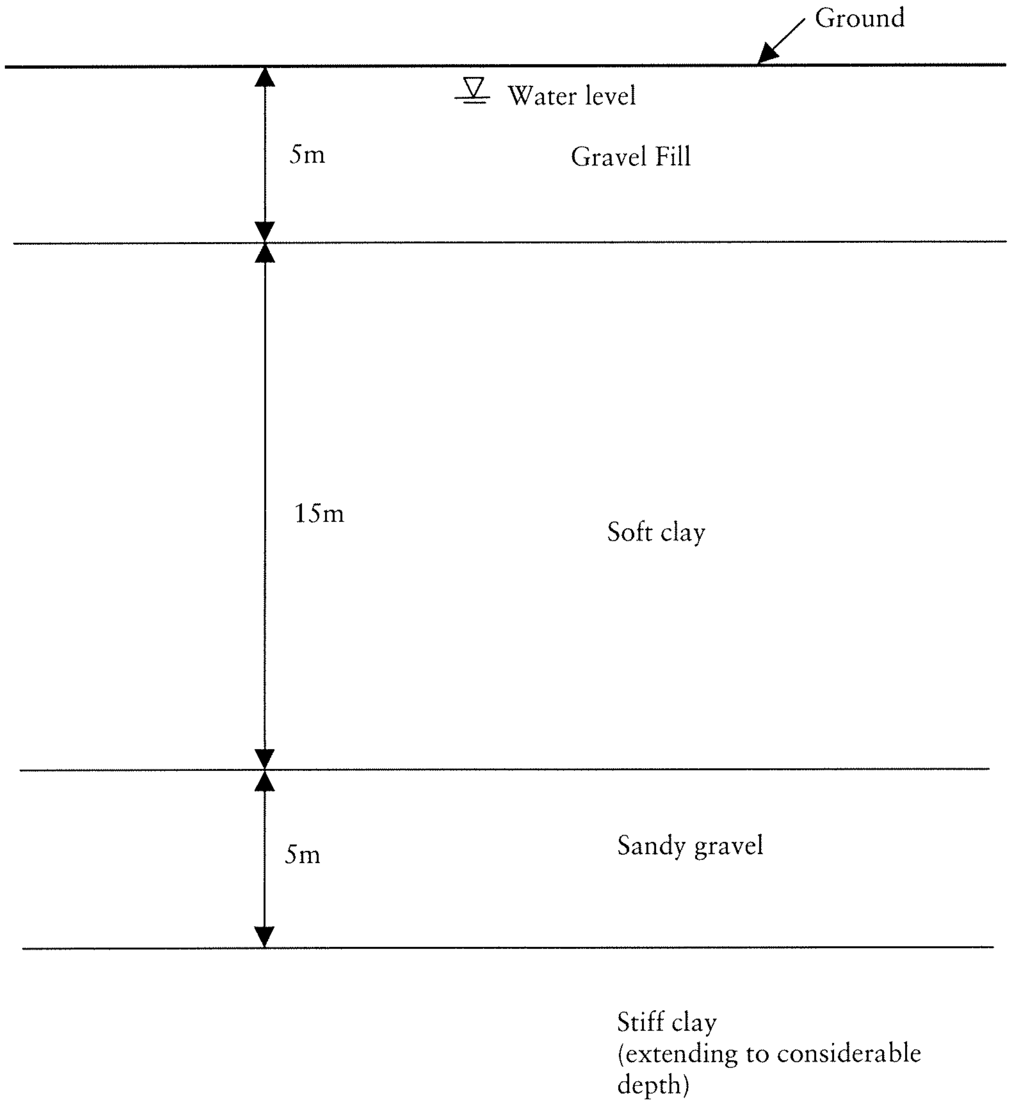

Fig. 2

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3 The roof of a cut-and-cover road tunnel consists of two spans, each 16m long as shown in Fig. 3. It is continuous over the central support. The ends are simply supported. The design ultimate load on the roof, including the self-weight of the roof itself and a suitable partial safety factor, is 150 kN/m^2. The roof is to be made from reinforced concrete, using steel of yield strength 460 N/mm^2 and concrete of cube strength 40 N/mm^2. Consider a typical one metre width of the roof.

(a) Calculate the maximum sagging and hogging bending moments in the roof. Note that the reaction at the internal support of a beam with two equal spans and uniformly distributed load is $\frac{5}{8}$ of the total load on the beam. [4]

(b) Calculate a suitable depth for the beam to carry the maximum sagging moment. Design suitable reinforcement. [6]

(c) Keeping the same depth of the roof over the central support, design suitable reinforcement at this position. [6]

(d) Sketch a suitable reinforcement layout. [4]

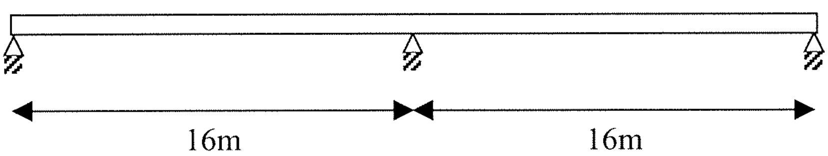

Fig. 3

SECTION B (Mechanical Engineering, Manufacture and Management)
*Do not answer more than **two** questions from this section*

4 (a) Briefly explain why sandwich construction is employed in some lightweight structural applications. What sort of cores are typically used in such applications? [5]

(b) Consider the cantilevered sandwich beam of length L, width b, core thickness c and face sheet thickness t (where $t \ll c$) as sketched in Fig. 4. The tensile yield strength of the face sheets is σ_Y^f and that of the core is σ_Y^c. The shear yield strength of the core is τ_Y^c. Estimate the *collapse load* of this beam assuming:

(i) face yielding collapse mode; [4]

(ii) core shearing collapse mode. [4]

(c) For a given collapse load P*, length L, width b and densities of face sheet and core materials ρ_f and ρ_c respectively, obtain an expression for the minimum weight of the sandwich cantilever beam. It may be assumed that the optimum design fails by face yield, and that the contribution of the core to the collapse strength is negligible. [7]

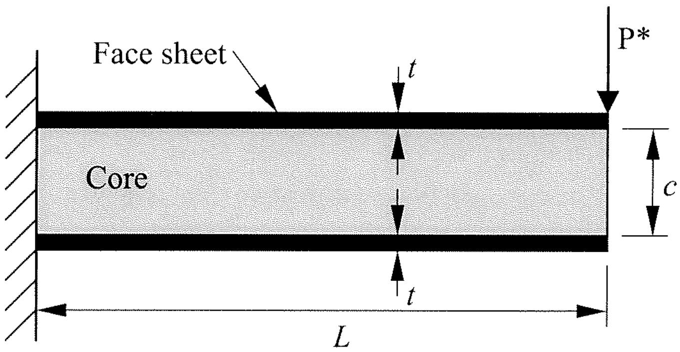

Fig. 4

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5 (a) Briefly describe *two* methods of manufacturing open-celled metal foams. [5]

(b) A compact heat sink made of open-celled metallic foam is proposed for the cooling of power electronic devices.

(i) An idealised open-cell foam has a cubic unit cell as sketched in Fig. 5. The edges of the cell consist of orthogonal cylinders with diameter d and length h. Assuming that $d << h$, derive expressions for the *relative density* and *surface area density* of the foam. [5]

(ii) Calculate the surface area density for a 20ppi (pores per inch) foam with a relative density 0.1, and hence determine if this foam qualifies for use as a compact heat sink. [5]

(iii) A prototype of the heat sink consists of a sandwich with two thin faces made from a heat-conducting solid, and a core made from an open-cell foam. Multi-chip modules are cooled by placing them on both face sheets. Discuss the design principles of such a heat sink, and explain why there exists an optimal relative density of foam which maximises the thermal efficiency of the heat sink. [5]

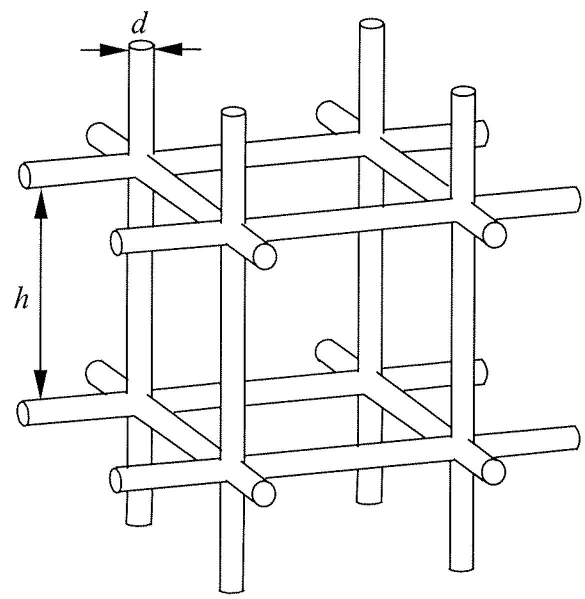

Fig. 5

6 (a) (i) List the principal contributions to the cost of producing a component made of a single material. [5]

(ii) Sketch the way in which cost varies with batch size for competing processes for making a component from a single material. Explain the reasons why some processes are economic at low batch sizes and others only at high. Suggest how "economically viable" regions of batch size might be extended, allowing a present-day process that is uneconomic at low batch sizes to extend its range of economic use. [5]

(b) (i) What is meant by a trade-off surface? Sketch such a surface, using mass and cost as competing objectives. Explain the nature of a value function, illustrating it on the sketch you have already made. [5]

(ii) The value function requires that performance metrics (such as mass in the above example) can be combined with cost to give a single function to be minimised. Explain how this is done, and how the necessary constants in the equation are determined. [5]

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SECTION C (Aerothermal Engineering)
*Do not answer more than **two** questions from this section*

7 (a) A two-shaft turbofan engine is fitted to an aircraft. At cruise conditions, the stagnation temperature T_{02} and stagnation pressure P_{02} at inlet to the engine are 260 K and 46 kPa respectively. The fan has a stagnation pressure ratio of 1.65 and an isentropic efficiency of 0.88. Find the stagnation pressure and the stagnation temperature at exit from the fan. [3]

(b) The ambient pressure is 29 kPa. Determine the exit velocity of the bypass nozzle. [2]

(c) After the core air-stream has passed through the fan, it enters the core compressor. The core compressor has a stagnation pressure ratio of 25. The stagnation temperature T_{03} at exit from the core compressor is 818 K. The high-pressure turbine has an isentropic efficiency of 0.88. The stagnation temperature T_{04} at inlet to the high-pressure turbine is 1600 K. Determine the stagnation temperature T_{045} and the stagnation pressure P_{045} at exit from the high-pressure turbine. [5]

(d) The bypass ratio is 9. The low-pressure turbine has an isentropic efficiency of 0.90. Determine the stagnation temperature T_{05} and the stagnation pressure P_{05} after the low pressure turbine. Hence determine the velocity V_9 of the core jet. [5]

(e) Determine the core mass flow rate required to produce an engine net thrust of 400 kN. [5]

Neglect the mass flow rate of the fuel. Assume that the combustion products behave as a perfect gas with the same properties as air. Neglect any losses in the ductwork and the propelling nozzles. Assume that for air, $\gamma = 1.4$, $R = 287\ \mathrm{J\,kg^{-1}K^{-1}}$ and $c_p = 1010\ \mathrm{J\,kg^{-1}K^{-1}}$

8 (a) Sketch the general arrangement of a two-shaft turbofan engine, labelling each component. Sketch a temperature-entropy diagram for the core stream. Sketch a separate temperature-entropy diagram for the bypass stream. Indicate the changes in thermodynamic states on the temperature-entropy diagrams that correspond to the components labelled in your sketch of the engine. Explain why the turbofan normally has more than one shaft. [8]

(b) Explain the importance of the *propulsive efficiency* of an engine. How does this affect the *specific fuel consumption*? Show that the propulsive efficiency may be given by the approximate expression

$$\eta_p = \frac{2V}{V + V_j}$$

where V is the flight speed and V_j is the jet velocity. State any assumptions that you make. Explain why most high thrust civil applications use bypass engines. What factors limit the upper value of the bypass ratio? [8]

(c) Explain why civil aircraft cruise at high altitude. Why should this altitude change during a transatlantic flight? [4]

9 (a) Explain what is meant by the terms *gross thrust* and *net thrust*. Under what circumstances is the net thrust equal to the gross thrust? Under what conditions is the net thrust zero? [4]

(b) An aircraft is fitted with turbojet engines. The aircraft cruises at Mach 0.9 where the ambient pressure is 19.3 kPa and the ambient temperature is 217 K. At cruise conditions, the net thrust provided by each engine is 50 kN and the mass flow rate through each engine is 66.5 kg s^{-1}. Neglecting the mass flow rate of the fuel, find the gross thrust produced by each engine. [4]

(c) The simple convergent propelling nozzle of each engine is choked. Explain why the gross thrust of each engine is determined by either of the two parameters

$$\frac{\dot{m}_f}{P_{02}\sqrt{T_{02}}} \quad \text{or} \quad \frac{\dot{m}_{air}\sqrt{T_{02}}}{P_{02}}$$

where $\dot{m}_f$ is the mass flow rate of fuel, T_{02} and P_{02} are the stagnation temperature and stagnation pressure at inlet to the engine respectively, and $\dot{m}_{air}$ is the mass flow rate of air. Explain why these two parameters have different forms. [6]

(d) A stationary test is carried out on the ground. The engine is set to operate at simulated cruise conditions. The ambient pressure is 101 kPa and the ambient temperature is 288 K. Find the mass flow rate of air $\dot{m}_{air}$ at the same conditions. [2]

(e) The throat area A_9 of the convergent propelling nozzle is 0.3 m^2. At cruise conditions, the velocity V_9 is 644 ms^{-1} and the static pressure P_9 is 99.8 kPa at nozzle exit. Determine the gross thrust of the engine during the test on the ground. [4]

Assume that the combustion products behave as a perfect gas with the same properties as air. Neglect any losses in the ductwork and the propelling nozzles. Assume that for air, $\gamma = 1.4$, $R = 287\ \text{J kg}^{-1}\text{K}^{-1}$ and $c_p = 1010\ \text{J kg}^{-1}\text{K}^{-1}$.

SECTION D (Electrical Engineering)

*Do not answer more than **two** questions from this section*

10 (a) Derive the relationship between conductivity and mobility in a material. [5]

(b) Silver has the face-centred cubic structure in which there are 4 atoms per unit cell of lattice constant 4.09Å and it has one conduction electron per atom. Its conductivity is $6.3\text{x}10^{7}\ \Omega^{-1}\text{m}^{-1}$. What is the mobility of its electrons? [3]

(c) What is the conductivity of a piece of silicon if it had the same mobility as silver and was doped to a donor concentration of $2\text{x}10^{20}\ \text{m}^{-3}$? [3]

(d) A designer desires to make a power depletion mode field effect transistor (FET) from a film of n-type semiconductor with a minimum transit time of 20 ps and a power dissipation of 2W. The semiconductor has a field-independent mobility of 0.1 $\text{m}^2\text{V}^{-1}\text{s}^{-1}$, a donor density of $10^{22}\ \text{m}^{-3}$, a film thickness of 10 μm and design rules which allow a maximum width to length (W/L) ratio of 50. Evaluate the FET dimensions, the drain voltage and the drain current. [9]

11 (a) Give evidence of both the quantum and particulate nature of light. [3]

(b) Calculate the energy of a photon of wavelength 400 nm in joules and in electron volts. [3]

(c) Using the time independent Schrodinger equation, derive an expression for the kinetic energy of electron standing waves in a one-dimensional box of length L and infinitely high sides. [8]

(d) A photon forms a standing wave in a one-dimensional box of length 200 nm. It resonates in the fundamental frequency with an electron wave of the same wavelength. What is the kinetic energy of the electron? [6]

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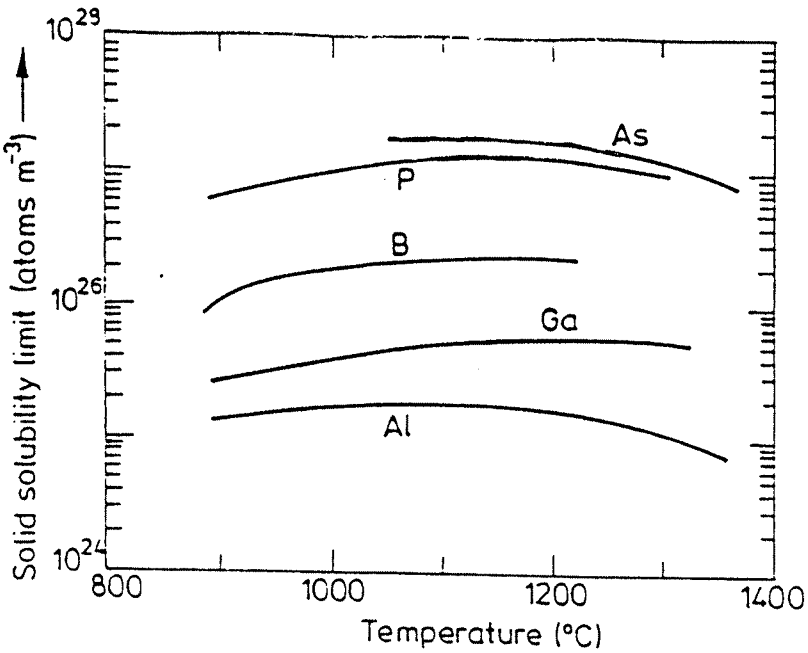
12 (a) The manufacture of a metal oxide semiconductor transistor (MOST), capable of operation at gigahertz frequencies, involves several etch steps. Compare and contrast the use of 'wet' and 'dry' etching for the various steps in making the MOST. Your answer should also indicate which of the above etch processes is more suitable for 'isotropic' and 'non-isotropic' etching applications. [6]

(b) For the device mentioned in section (a), n^+ doped source and drain regions are required. These can be fabricated by using phosphorous diffusion. Give another example of a dopant which can be utilised and explain why it acts as a donor. Compare and contrast diffusion with another method which is normally employed to produce such doped regions. [6]

(c) In our particular case we have chosen to use phosphorous diffusion from an impurity saturated vapour to produce the n^+ regions. The p-type silicon substrate contains 5×10^{22} acceptor atoms per m^3. From Fig. 6 and Fig. 7, estimate the depth of the n^+p junction formed by such a diffusion at 1050°C for 1.5 hours. Is this a sensible process decision? State any assumptions made. [8]



The solid solubility versus temperature data for a range of atoms on silicon

Fig. 6

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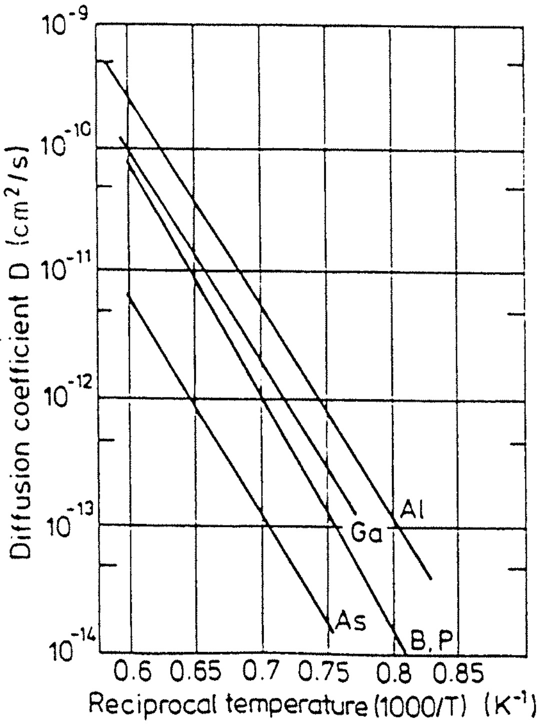

Fig. 7

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SECTION E (Information Engineering)

*Do not answer more than **two** questions from this section*

13 You are required to design a protocol for remoting displays from digital devices based on a "thin client" approach. The protocol should be able to remote the display of any device to the display of any other device.

(a) Describe the advantages of a "stateless" architecture [2]

(b) List the basic protocol interactions [6]

(c) Give four pixel data encodings [8]

(d) Indicate how the implementation can minimise use of system resources [4]

14 This question concerns process management in an operating system.

(a) (i) What benefits can a multiprocessing environment provide with respect to resource and processor utilisation? [1]

(ii) Each task in a multiprocessing system may be either *running, runable* or *blocked*. What is meant by each of these terms, and how may a process move between these possible states? [5]

(iii) When selecting which of the candidate processes to run next, one of a number of policies may be chosen depending on the characteristics of the processing to be performed by the system. Briefly describe the operation of the round robin and priority based scheduling policies. [3]

(cont.

(iv) What is the difference between preemptive and non-preemptive scheduling mechanisms? [2]

(b) Processes may be classified as being either compute-bound or I/O bound.

(i) How might an operating system determine if a process is I/O or compute bound?

(ii) Depending on whether the system is I/O or compute bound, explain how, and why, the choice of scheduling mechanism to be used might differ? [4]

(c) The appearance of tasks running concurrently may also be achieved using multi-threading.

(i) What is the difference between a process and a thread? Your answer should include a brief description of the information that needs to be stored for each of these primitives, as well as the actions performed when switching between different processes or threads.

(ii) Why might multi-threading be more appropriate than multi-processing for a heavily loaded WWW server? [5]

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15 Unlike a desktop machine wearable devices are mobile in nature, so will frequently be disconnected from a wire power source or network connection.

(a) Briefly compare and contrast the 'fat' and 'thin' models of mobile computing. How may a 'thin' device provide access to computing facilities equivalent to that provided by the 'fat' model?

What security implications are there to consider, when considering these two different usage models? [5]

(b) When not connected to a wired network, communication to a mobile device may still be provided via a wireless connection. Compared with a wired network, what additional issues must be taken into account with such a connection?

Why might a 'traditional' network protocol, such as TCP/IP, not be the most appropriate choice in such a mobile computing environment?

A mobile device will also usually be powered by batteries, which provide only a limited amount of power. How may this resource be conserved, whilst still maintaining acceptable network connectivity?

Give examples of some of the additional techniques that can be used to conserve power in other parts of the wearable computer system. [10]

(c) A wearable computing system typically must be able to perform its task reliably over a long period of time. What protection mechanisms can be used to enhance reliability?

What hardware support is required to implement these mechanisms? [5]

END OF PAPER