ENGINEERING TRIPOS PART IIB

Friday 4 May 2007 9 to 10.30

Module 4B6

SOLID STATE DEVICES AND CHEMICAL/BIOLOGICAL SENSORS

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.*

Attachments: Formulae sheet (1 page)
One extra copy of Fig. 2 (Question 4)

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

1 An ideal p-type silicon MOS capacitor has the following parameters:

oxide thickness	$d = 10^{-7} m$
oxide dielectric constant	$\varepsilon_i = 3.9\varepsilon_0$
semiconductor dielectric constant	$\varepsilon_s = 11.9\varepsilon_0$
acceptor concentration	$N_A = 10^{21} m^{-3}$

A voltage pulse of amplitude V is applied to the capacitor, resulting in a surface potential $\psi_s = 4\,\mathrm{V}$, before any appreciable inversion charge is generated (deep depletion).

(a) Starting from Poisson's Equation:

$$\frac{d^2\psi}{dx^2} = -\frac{\rho(x)}{\varepsilon_s}$$

Prove that the total charge per unit surface in the semiconductor is given by:

$$Q_B = -\left[2\varepsilon_s q N_A \psi_s\right]^{1/2}$$ [30%]

(b) Calculate V . [20%]

(c) Calculate the length of the depletion region. [10%]

(d) Calculate the device capacitance per unit area under these conditions. [10%]

(e) Explain the behaviour of the capacitance as a function of V for a MOS:

(i) in deep depletion;

(ii) after the formation of the inversion layer, when the frequency of the AC voltage employed to measure the capacitance is low (~1 Hz) and when it is high (~100 kHz). [30%]

2 (a) Starting from the current equation in one dimension (see attached formulae), prove that, if $\frac{dE_F}{dx} = 0$, where E_F is the Fermi energy, then $J = 0$. [30%]

(b) Calculate the value of the electric field component parallel to the channel, at the drain end $(y = L)$, for a MOSFET with $L = 20\,\mu\text{m}, V_T = 0.5\,\text{V}$, when $V_{GS} = 5\,\text{V}$ and $V_{DS} = 3\,\text{V}$. Assume that the conductance G along the channel is given by:

$$G(y) = K[V_{GS} - V_c(y) - V_T]$$

Assume also that V_T is independent of y and K is a constant. [70%]

3 (a) With the aid of a band diagram, discuss the effect of the work function difference between the metal gate and the semiconductor in a MOSFET. [20%]

(b) Explain how a MOSFET can be used as a Hydrogen gas sensor. [30%]

(c) Explain how an Ion Sensitive Field Effect Transistor operates as a pH sensor. [50%]

(TURN OVER

4 (a) Explain what is meant by:

(i) ferroelectric material;
(ii) polarization;
(iii) domains. [10%]

(b) Describe the structure and the principle of operation of a ferroelectric field-effect transistor (F-FET). [20%]

(c) With reference to the circuit diagram of Fig. 1, explain how a one-transistor one-capacitor (1T/1C) ferroelectric memory cell operates for its WRITE and READ operation. Include a sketch of the sensed charge versus applied voltage curve for the READ operation. [40%]

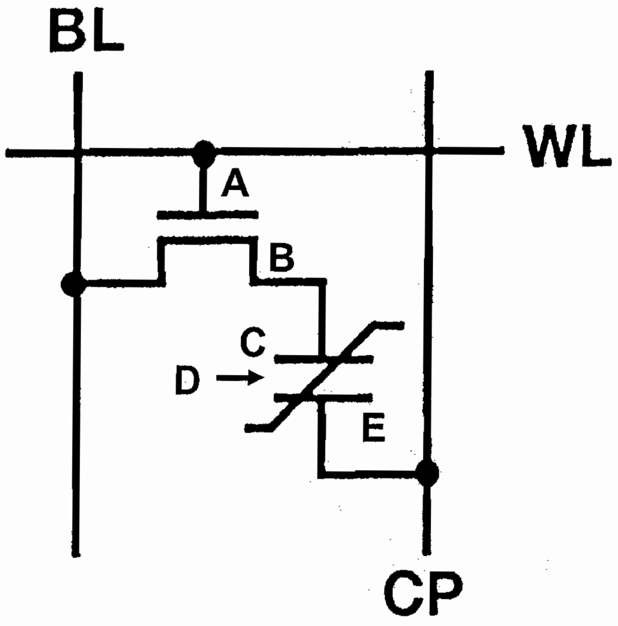

Fig. 1

(d) Using the working sheet copy of Fig. 2, mark the parts A, B, C, D and E as shown in Fig. 1 at the corresponding places for both planar and stacked structures in Fig. 2. Describe the function and possible materials for each part. Give a brief comparison of the advantages and disadvantages for these two structures. [30%]

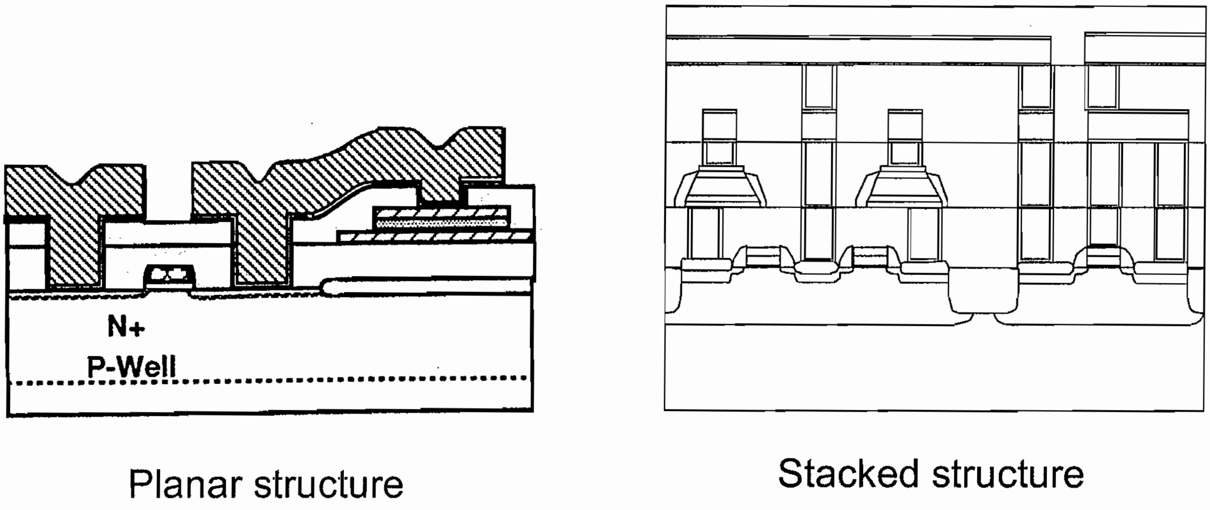

Fig. 2

5 (a) What is the giant magneto-resistance (GMR) effect? (Including its principle, basic elements and their functions). [30%]

(b) Explain the performance of a GMR unit, based on the experimental results shown in Fig.3. How could the $\Delta\rho/\rho > 100\%$? [40%]

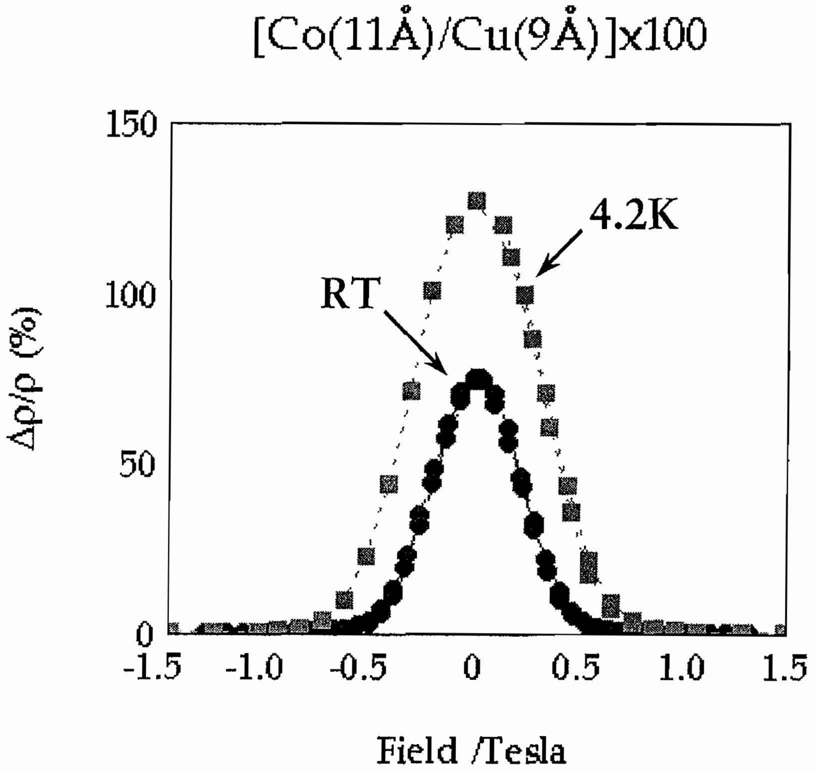
[Co(11Å)/Cu(9Å)]x100

Fig. 3

(cont.

(c) With reference to Fig. 4, explain the WRITE operation of a pseudo spin valve (PSV) magnetic random access memory (MRAM) cell. [30%]

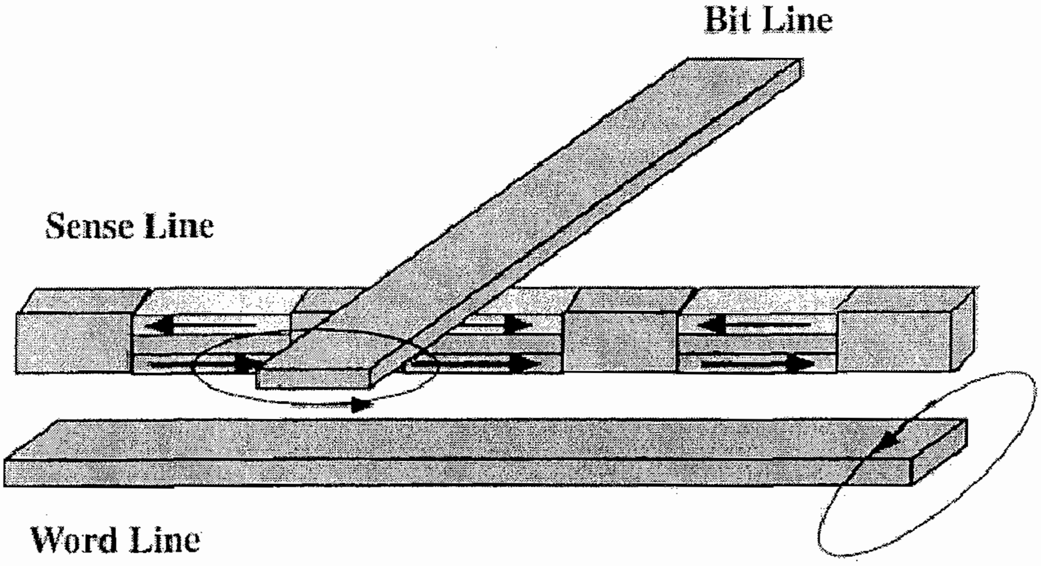

Fig. 4

END OF PAPER

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Formulae

$$J_n = q\mu_n nF + qD_n \frac{dn}{dx}$$

$$D_n = \mu_n \frac{kT}{q}$$

$$I_D = W\ G(y)\frac{dVc}{dy}$$

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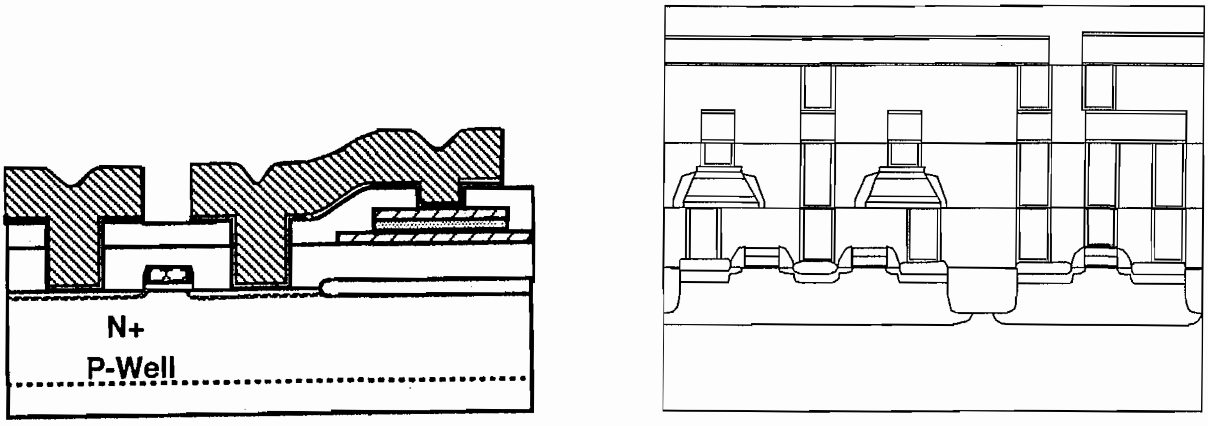

Planar structure

Stacked structure

Fig. 2

Working sheet for Q 4
(may be handed in with your script)