ENGINEERING TRIPOS PART IIB

Friday 6 May 2011 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.*

Attachment: Formulae and Constants sheet (1 page)

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
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 (a) Define the threshold voltage for a MOS Capacitor. [10%]

(b) An ideal p-type silicon MOS capacitor has the following parameters:

oxide thickness	$d = 2.0\times10^{-7}$ m
oxide dielectric constant	$\varepsilon_i = 3.9\varepsilon_0$
semiconductor dielectric constant	$\varepsilon_S = 11.9\varepsilon_0$
intrinsic carrier concentration	$n_i = 1.45\times10^{16}$ m^{-3}
acceptor concentration	$N_A = 2.0\times10^{21}$ m^{-3}
Effective Density of States in Conduction Band	$N_C = 2.08\times10^{25}$ m^{-3}
Effective Density of States in Valence Band	$N_V = 1.04\times10^{25}$ m^{-3}

Calculate the threshold voltage of this device at room temperature. [30%]

(c) A MOS capacitor with the above parameters contains interface states at the silicon/SiO_2 interface. These states are acceptor-like, that is they carry a charge $-q = -1.6\times10^{-19}$ C when occupied, and are neutral when empty. Their density, D_{it}, is constant throughout the bandgap: $D_{it} = 10^{16}$ m^{-2} eV^{-1}.

Calculate the threshold voltage at room temperature in this case.

Assume that the Fermi function $F(E)$ can be approximated as a step function:

$$F(E) = 1 \quad \text{for } E \leq E_F$$
$$F(E) = 0 \quad \text{for } E > E_F.$$

[30%]

(d) Discuss whether the result of the calculation in (c) would change, if the correct Fermi function is employed:

(i) for the above D_{it}

(ii) for any D_{it} [30%]

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

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

(c) Explain the formation of the electrochemical double layer:

(i) at the interface between a metal and an electrolyte;

(ii) at the interface between an insulator such as SiO_2 and an electrolyte. [20%]

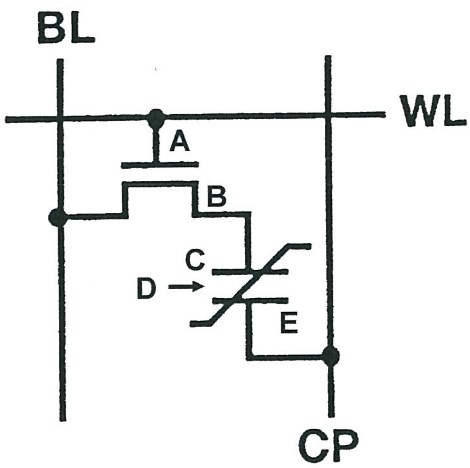
(d) Explain how the system (ii) can be used as a pH sensor. [30%]

3 (a) Explain the meaning of the following terms:

(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.

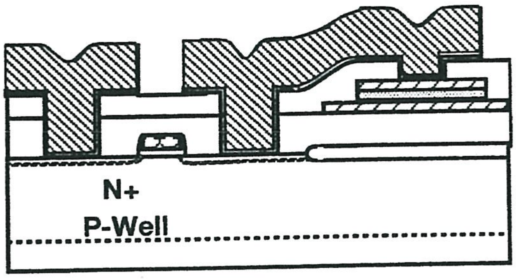


[40%]

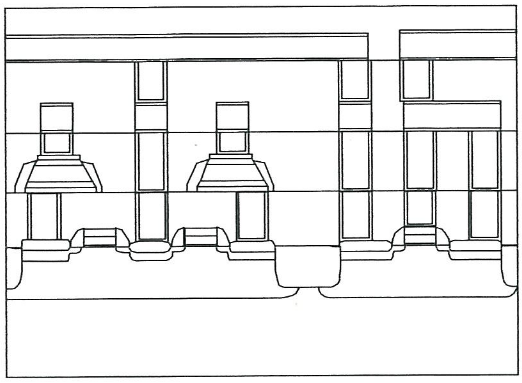
Fig. 1

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

(cont.



Planar structure



Stacked structure

Fig. 2

(TURN OVER

4 (a) Explain 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. Explain why $\Delta\rho/\rho$ can be greater than 100%. [40%]

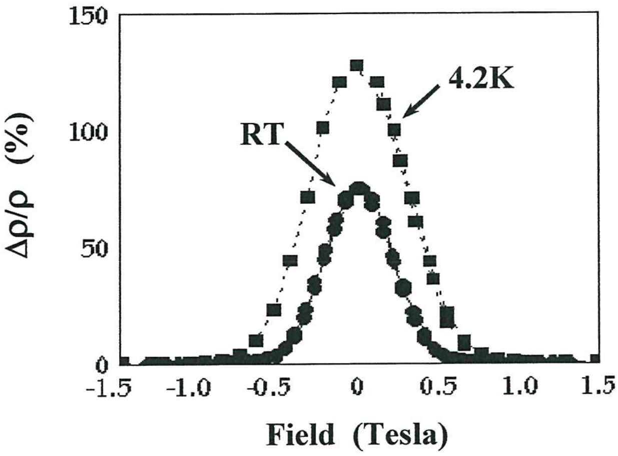


Fig. 3

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

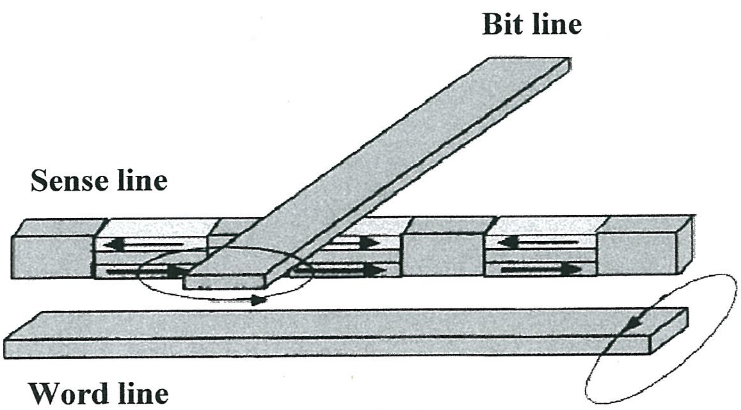


Fig. 4

END OF PAPER

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Module 4B6
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Formulae and constants

$\varepsilon_0 = 8.85 \times 10^{-12}$ farad m^{-1} permittivity in vacuum

$k = 1.38 \times 10^{-23}$ Joules K^{-1} Boltzmann's constant

Fixed charge in the depletion region:

$$Q_B = -\left(2\varepsilon_S q N_A \psi_S\right)^{\frac{1}{2}}$$