Version DPC/4.1

EGT3
ENGINEERING TRIPOS PART IIB

Mon 5 May 2014 14.00 to 15.30

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.*

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
Attachment: 4B6 formulae and constants sheet (1 page)
Engineering Data Book

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

1 (a) Explain the meaning of deep depletion in an MOS capacitor. [20%]

(b) Calculate the voltage applied to an ideal p-type silicon MOS capacitor in deep depletion, for 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}
surface potential	$\psi_S = 4$V

[30%]

(c) (i) Explain what is meant by linear and saturation regimes in a MOSFET. [15%]

(ii) Sketch the conductance as a function of position in the channel and identify the pinch-off region, when present:

(1) in the linear regime;
(2) for $V_{DS} = V_{Dsat}$;
(3) for $V_{DS} > V_{Dsat}$. [15%]

(d) What is the value of the channel potential at the left hand boundary of the pinch-off region? [20%]

Note: Fixed charge per unit area in the depletion region, where symbols have their standard meaning:

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

2 (a) Describe the use of the polymerase chain reaction (PCR) to selectively replicate a given nucleotide sequence in large amounts from any DNA sample that contains it. [40%]

(b) Starting with one double-stranded DNA molecule, one would like to amplify a 300-nucleotide-pair sequence contained within it. How many cycles of PCR amplification will be needed to produce 100ng of this DNA, given that each nucleotide has an average molecular weight of 330g/mole? (100ng is an amount that can be easily detected after staining with a fluorescent dye.) [20%]

(c) Electrochemical Impedance Spectroscopy (EIS) is proposed for DNA detection. Draw a standard three-electrode cell suitable for this application. Figure 1 shows the self-assembled single-stranded DNA probe and Mercaptohexanol co-immobilized on to the gold electrode. The buffer solution used in the cell has a redox couple Ferricyanide $[Fe(CN)_6]^{3-}$ and Ferrocyanide $[Fe(CN)_6]^{4-}$. Construct an equivalent electrical circuit model to estimate the impedance of the system, comment on each term. Sketch the frequency response (Nyquist plot) of the equivalent electrical circuit. [20%]

(d) With reference to the equivalent electrical circuit model in (c), explain how single-stranded target DNA can be detected with EIS. Comment on ways to improve the sensitivity of the detection technique. [20%]

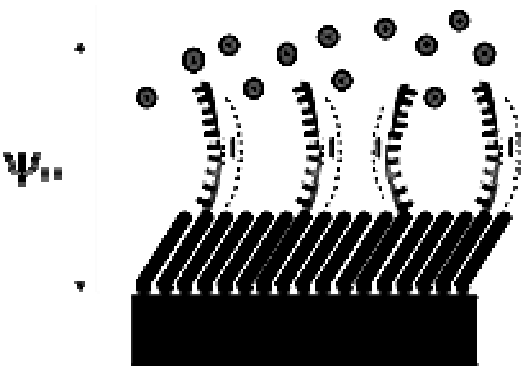


Fig. 1

(TURN OVER

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 Figure 2, 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%]

(c) Mark the parts A, B, C, D and E in Figure 2 at the corresponding places for both planar and stacked structures in Figure 3. Describe the function and possible materials for each part. Give a brief comparison for the advantages and disadvantages of these two structures. [30%]

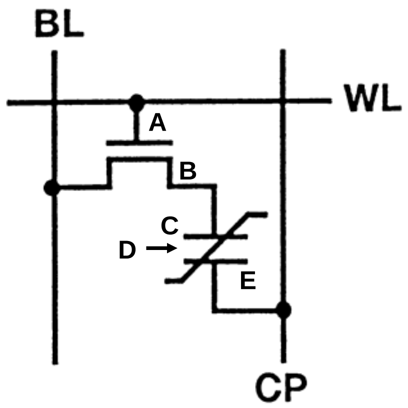
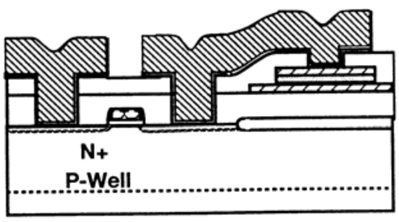
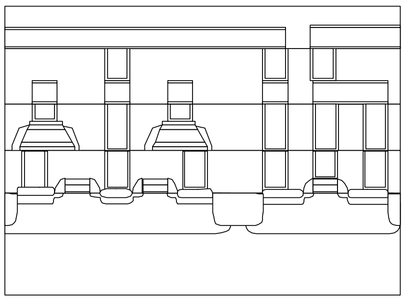


Fig. 2



Planar structure



Stacked structure

Fig. 3

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 Figure 4, and why the relative change of resistivity, $\Delta\rho/\rho$, can be greater than 100%. [40%]

(c) With reference to Figure 5, explain the WRITE operation of a pseudo spin valve (PSV) magnetic random access memory (MRAM) array. [30%]

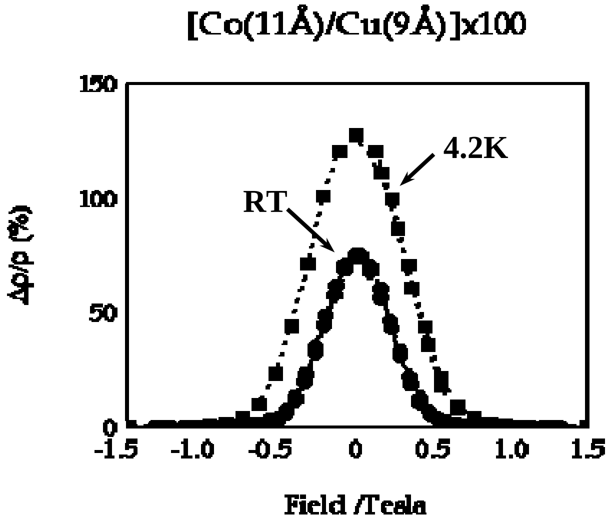


Fig. 4

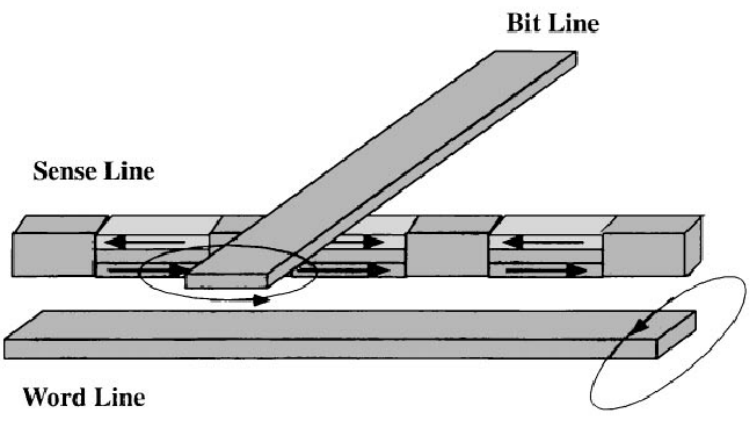


Fig. 5

END OF PAPER

THIS PAGE IS BLANK

ENGINEERING TRIPOS PART IIB

Module 4B6

SOLID STATE DEVICES AND CHEMICAL/BIOLOGICAL SENSORS

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