Version DPC/2

EGT3
ENGINEERING TRIPOS PART IIB

Monday 23 April 2018 2 to 3.40

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

10 minutes reading time is allowed for this paper at the start of the exam.

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

1 (a) Define the threshold voltage for a Metal-Oxide-Semiconductor (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) An MOS capacitor with the above parameters contains interface states at the silicon/SiO_2 interface. These states are acceptor-like, that is each state carries a charge of -1.6×10^{-19} C when occupied and is 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} [15%]

(ii) for any D_{it} [15%]

State all assumptions and approximations made.

2 (a) Draw the circuit diagram of an MOS Field Effect Transistor (MOSFET) inverting voltage amplifier and explain the Miller effect in such a circuit. [30%]

(b) If an inverting voltage amplifier has a gain A and Miller capacitance C_{GD}, write the expressions for:

(i) the input current due to the Miller capacitance; [10%]

(ii) the effective input capacitance; [10%]

(iii) the ratio of the amplifier's upper 3 dB frequencies with and without the Miller capacitance. [20%]

(c) Discuss why it is important to minimize the Miller effect and how to do so at the device level. [30%]

State all assumptions and approximations made.

3 (a) The circuit diagram of a Ferroelectric Random Access Memory (FRAM) cell is shown in Fig. 1. Explain how to write and read a bit of information, that is the WRITE and READ operations, in terms of the different voltage levels that are applied to the terminals BL, WL and CP. [50%]
[Hint: Sense amplifier for read-out is connected to BL.]

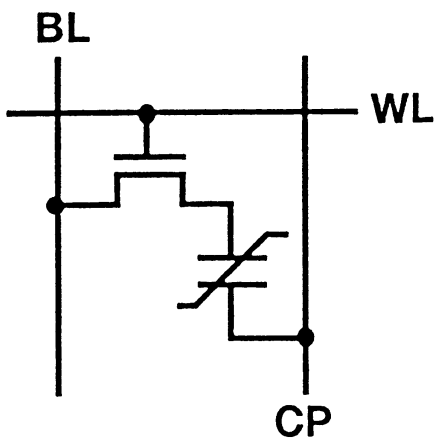

Fig. 1

(b) The ferroelectric capacitor in Fig. 1 is made of a ferroelectric material and its hysteresis curve is shown in Fig. 2. It has dimensions of 100 nm in thickness and 250 nm by 250 nm in area. Estimate:

(i) the remnant polarisation and coercive field of the material; [10%]

(ii) the amount of charge flowing into the BL during a READ operation with a +5 V applied to CP:

a. when the initial information stored in this memory cell is State “1” (positively polarised); [10%]

b. when the initial information stored in this memory cell is State “0” (negatively polarised). [10%]

(iii) the energy consumed by the ferroelectric capacitor due to polarisation switching. [20%]

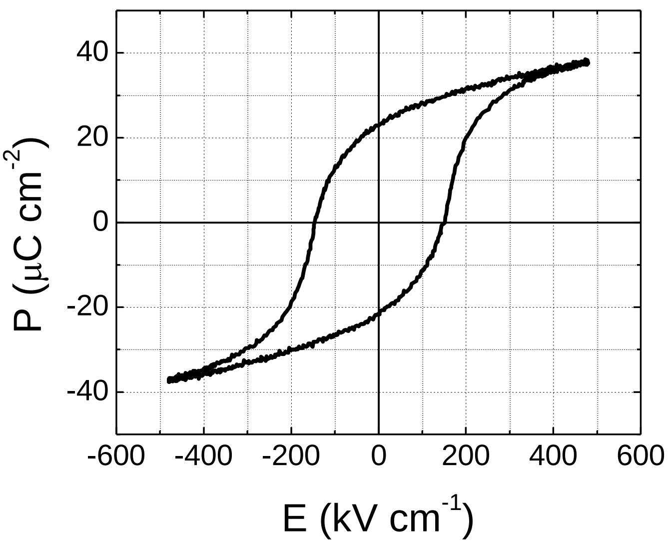

Fig. 2

State all assumptions and approximations made.

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4 (a) Explain:

(i) how a Magnetic Tunnel Junction (MTJ) works in the Current-Perpendicular-to-Plane (CPP) and Current-In-Plane (CIP) configurations, as shown in Fig. 3; [20%]

(ii) whether the lower Co layer, which is not in direct contact with the measurement probes in the CIP configuration, has any impact on the measured current and why; [20%]

(iii) how a bit of information is stored and which physical quantities are read-out. [10%]

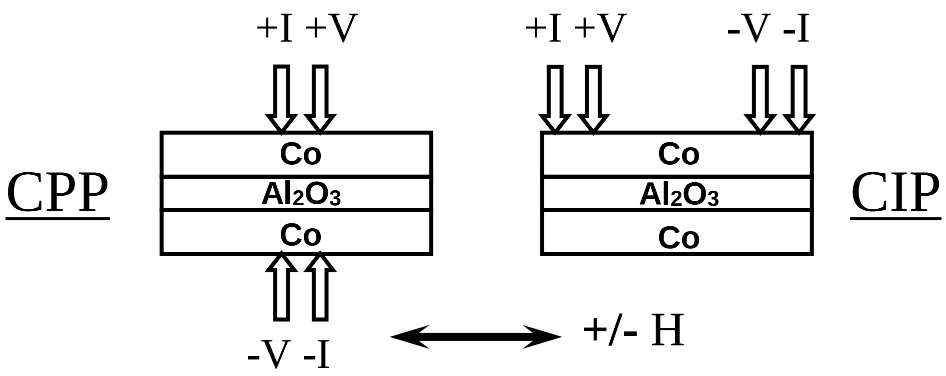


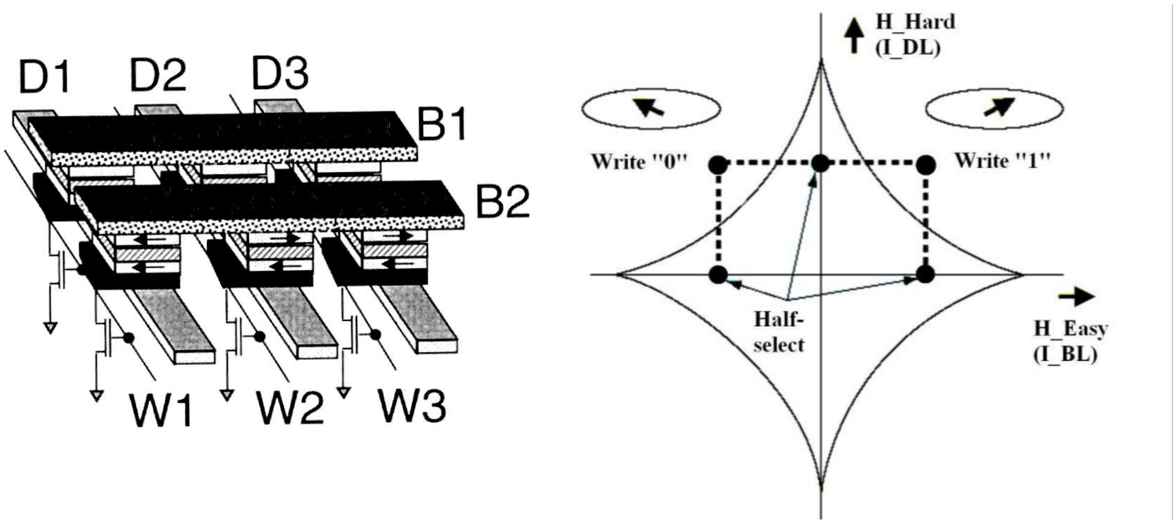
Fig. 3

(b) A sketch of a Magnetic Random Access Memory (MRAM) array is shown in Fig. 4(a). For a given cell (say B2-W2), explain without reproducing Fig. 4(a):

(i) how to write a bit of information into the cell, with reference to Fig. 4(b); [30%]

(ii) how to read the stored information; [10%]

(iii) the importance of the physical geometry of the device. [10%]



(a) (b)

Fig. 4

State all assumptions and approximations made.

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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

Bulk charge in the depletion region:

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