ENGINEERING TRIPOS PART IIB

Friday 1 May 2009 9 to 10.30

Module 4B6

SOLID STATE DEVICES AND CHEMICAL AND 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 sheet (1 page)

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
Single-sided script paper	Engineering Data Book
Graph paper	CUED approved calculator allowed
	Constants and formula at the end of the paper

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 MOSFET. [20%]

(b) Calculate the threshold voltage for a silicon n-MOSFET with the following parameters:

Gate Oxide (SiO_2) thickness $d = 10$ nm

Acceptor Concentration $N_A = 10^{15}$ cm^{-3}

Assume the device is ideal and V_{DS} is negligibly small. [40%]

(c) N-Channel MOSFETs with the above parameters are fabricated and, due to a fault in the process, some fixed charge is present at the oxide/semiconductor interface.

From the I_D-V_{GS} data below, obtained for $V_{DS} = 0.001$ V, determine the density and sign of the fixed charge.

V_{GS}(V)	I_D(μA)
1.0	1.43
1.4	1.89
1.8	2.35
2.2	2.81
2.6	3.27
3.0	3.73

[40%]

2 (a) Draw a high frequency C-V plot for MOS capacitors on an n-type and a p-type semiconductor:

(i) in the ideal case;

(ii) in the presence of a positive fixed charge in the oxide. [35%]

(b) Discuss the origin of interface states for the SiO_2 / Si system and explain with a sketch the effect on the C-V characteristics in the case of a p-type semiconductor. [35%]

(c) Discuss the physical origin of gap states in amorphous silicon and the effect that these states have on thin film transistor (TFT) electrical characteristics. [30%]

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3 (a) The circuit diagram of a 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.
[*Hint: The sense amplifier for read-out is connected to the BL.*] [50%]

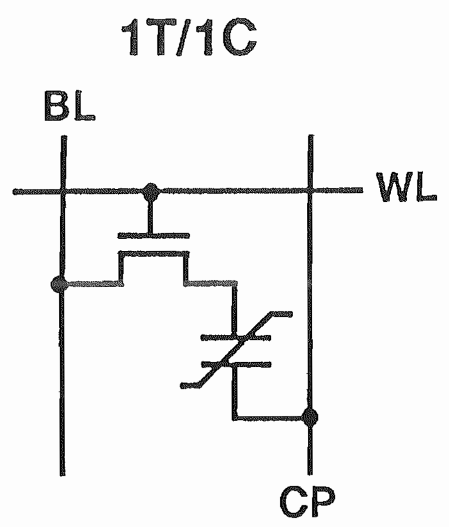

Fig. 1

(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 100nm in thickness and 250nm square in area. Estimate:

(i) the remnant polarisation and coercive field of the material;

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

(a) when the initial information stored in this memory cell is State "1" (positively polarised);

(b) when the initial information stored in this memory cell is State "0" (negative polarised).

(iii) the energy consumed by the ferroelectric capacitor due to polarisation switching. [50%]

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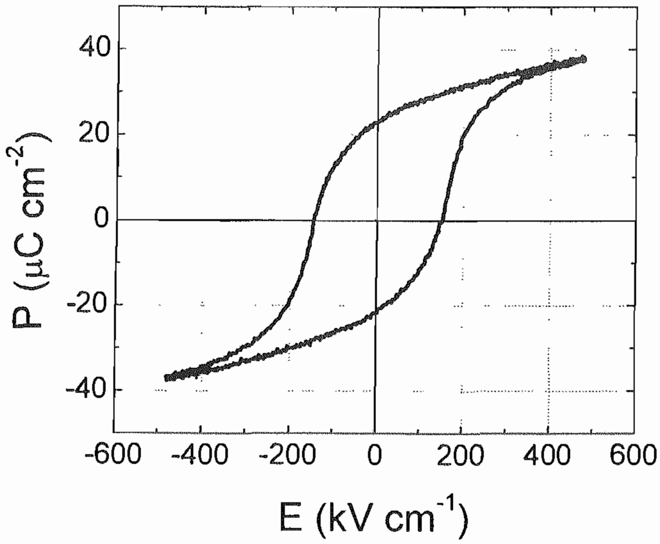

Fig. 2

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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, respectively;

(ii) whether the lower Co layer, which is not in contact in the CIP configuration, has any impact on the measured current and why;

(iii) how a bit of information is stored and which physical quantities are read-out. [50%]

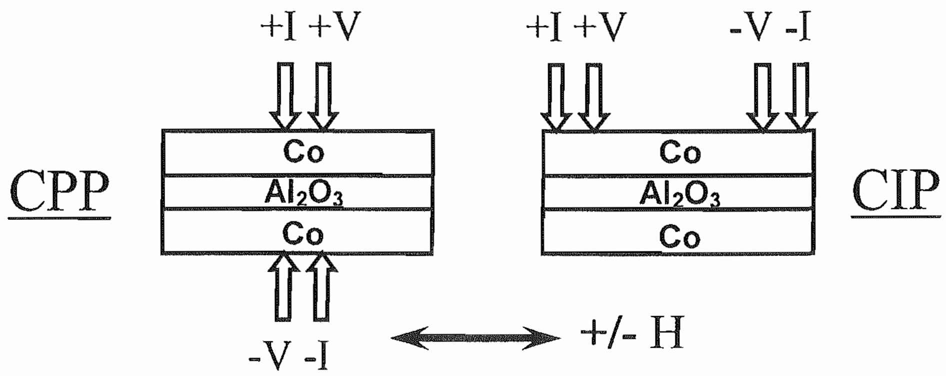


Fig.3

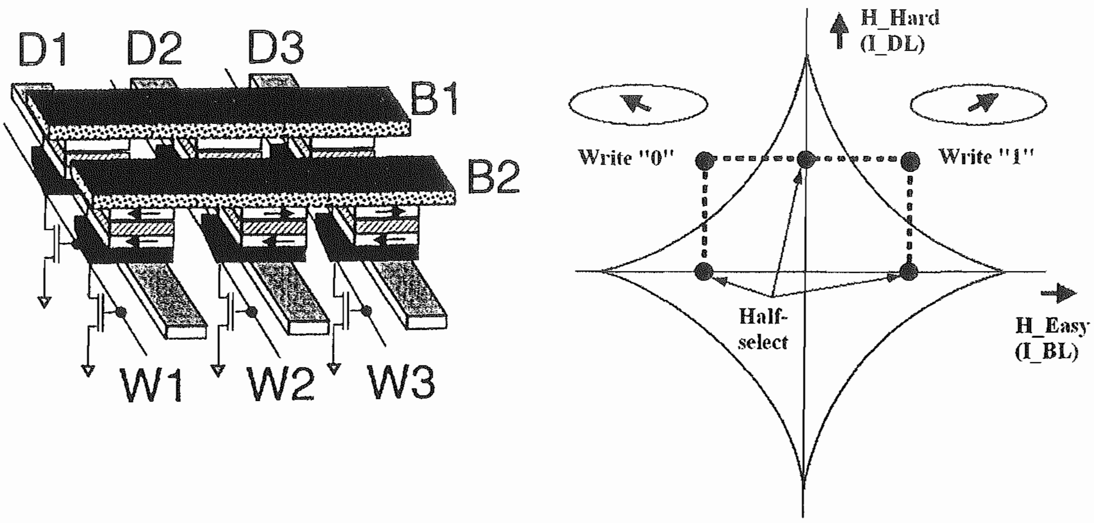
(b) A sketch of a MRAM array is shown in Fig. 4(a). For a given cell (say B2-W2), explain:

(i) how to write a bit of information into the cell, with reference to the diagram in Fig. 4(b);

(ii) how to read the stored information;

(iii) the importance of the physical geometry of the device. [50%]

(cont.



(a) (b)

Fig. 4

END OF PAPER

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Constants and Formulae

** Note that not all the information below may be needed to answer the questions*

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

$k=1.38\ 10^{-23}$ Joules $^0K^{-1} = 8.625\ 10^{-5}$ eV $^0K^{-1}$ Boltzman constant

$kT/q = 0.025V$ at $T=300K$

$N_c=2.8\ 10^{25} m^{-3}$

$N_v=1.04\ 10^{25} m^{-3}$

Eg(silicon)=1.12eV

ε_i (silicon dioxide) = $3.9\varepsilon_0$

ε_s (silicon)= $11.9\varepsilon_0$

$n=N_C \exp((E_F-E_C)/kT))$

$p=N_V \exp((E_V-E_F)/kT))$

$(np)^{0.5} = n_i = 6.6\ 10^{15}\ m^{-3}$

$$Q_B = -[2\varepsilon_s q N_A \psi_s]^{\frac{1}{2}}$$

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Answers to numerical questions.

Q1 b) V_T=0.659V; c) Q_F=+3.12 10^{-7}C

Q3 b) (i) Pr = 23 μC cm^{-2}; Ec = 150 kV cm^{-1}; (ii) $\Delta Q_{"1"}$ =38x10^{-15} C, $\Delta Q_{"0"}$ =9.4x10^{-15} C;

(iii) ΔE=4x10^{-14} J