ENGINEERING TRIPOS PART IIB

Friday 2 May 2008 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.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed
Supplementary pages: None

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) 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	$\psi_S = 4V$

[30%]

(c) Explain what is meant by linear and saturation regimes in a MOSFET.

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

(i) in the linear regime;

(ii) for $V_{DS} = V_{Dsat}$;

(iii) for $V_{DS} > V_{Dsat}$ [30%]

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

Note:

The fixed charge per unit area in the depletion region, where symbols have their standard meaning is given by

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

2 (a) Explain how the double layer originates at a metal-electrolyte and at an insulator-electrolyte interface. Discuss why the double layer potential is important for biosensor applications. Give examples. [50%]

(b) A water-based electrolyte, in contact with a planar electrode, contains positive and negative ions in equal concentrations, $n^+ = n^- = n_0 = 10^{24}$ ion m^{-3}. Each ion carries a charge equal in magnitude to $q = 1.6 \times 10^{-19}$ Coulomb.

Prove that Poisson's Equation for this system can be written in the following form:

$$\frac{d^2\psi}{dx^2} = -\frac{qn_0}{\varepsilon}\left[\exp\left(-\frac{q\psi(x)}{kT}\right) - \exp\left(\frac{q\psi(x)}{kT}\right)\right]$$

where ψ is the double layer potential, x is the direction normal to the interface, k is Boltzmann's constant and $\varepsilon = 80\varepsilon_0$ is the dielectric constant of water. State all assumptions made. [20%]

(c) Assuming that the potential drop in the electrolyte is small compared to kT/q, where k is Boltzmann's constant, find the ratio $\psi(x)/\psi(0)$ for $x = 2 \times 10^{-9}$ m and $T = 300K$. State all assumptions made. [30%]

3 (a) For the ferroelectric thin film material shown in Fig. 1, please estimate the:

(i) remnant polarisation; [10%]

(ii) coercive field; [10%

(iii) energy density consumed in a full switching cycle. [10%]

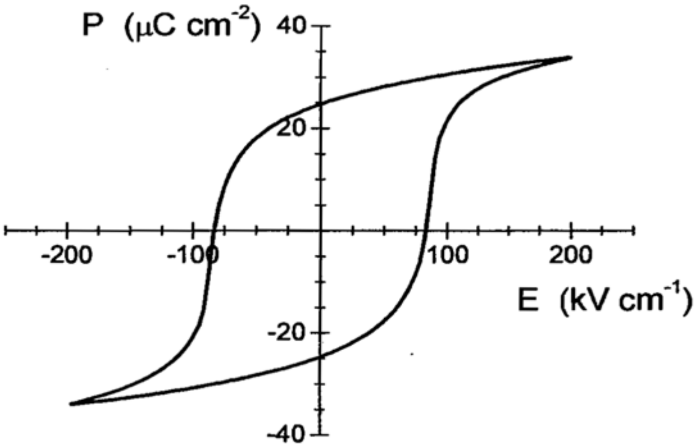

Fig. 1

(b) A ferroelectric thin film capacitor in a FRAM cell is made of the ferroelectric material shown in Fig. 1 with dimensions of 150 nm thickness and 0.18μm x 0.18μm square.

(i) If we apply a voltage across it in the form of a positive step function with a height of +3V, what will be the switching charges if the initial information stored in this memory cell was of State '1' (positively polarised) and State '0' (negative polarised), respectively? [15%]

(cont.

(ii) If the bit line parasitic capacitance, which is utilised as a sensing capacitor, is 2pF, what are the sensed voltage levels for these two states, respectively? [15%]

(iii) Theoretically, how small can this capacitor be in order to maintain its original function as a memory cell, given that the Read-out sense amplifier has a resolution of 1mV? [20%]

(c) Figure 2 shows the results of an accelerated reliability test for the above memory cell. What are the projected life times of this device at 80°C and 30°C, respectively? (Hint: assume $t_{failure} \sim \exp(+\Delta E/kT)$, where ΔE is a constant and k the Boltzmann constant.) [20%]

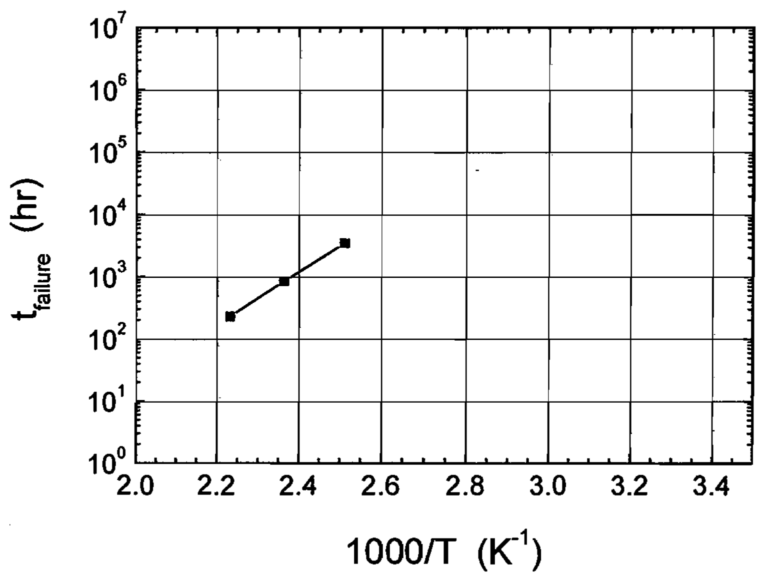

Fig. 2

4 (a) A magnetic tunnel junction (MTJ) is operating in current-perpendicular-to-plane (CPP) configuration. It consists of two magnetic layers made of Co, which are separated by a thin non-magnetic layer made of Cu with a thickness of t_{Cu}, as shown in Fig. 3. The free energy of magnetic interaction, *E*, between the two Co layers can be described in the form of $E = -J\vec{M}_{Co,1} \cdot \vec{M}_{Co,2}$, where $\vec{M}_{Co,1}$ and $\vec{M}_{Co,2}$ are the in-plane magnetisations of the two Co layers, respectively, and J the exchange integral. Assume that the exchange integral is of RKKY-type interaction, i.e. $J \sim \cos(2\pi\alpha t_{Cu})/(2\pi\alpha t_{Cu})^3$, where α is a constant. Sketch the exchange integral vs t_{Cu} and mark the regions of high and low magneto-resistance (HMR and LMR) when the external magnetic field is zero. [50%]

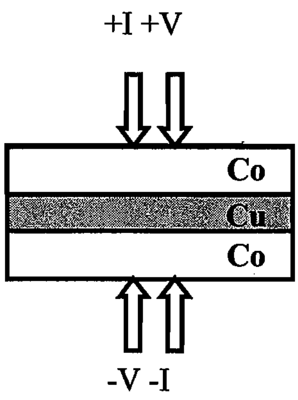

Fig. 3

(cont.

(b) The circuit representation of an MRAM cell is shown in Fig. 4. Use it to:

(i) draw a memory matrix linked by Bit-line, Word-line and Digit-line;

(ii) describe how to Read and Write a bit of information to and from a chosen cell, respectively. [50%]

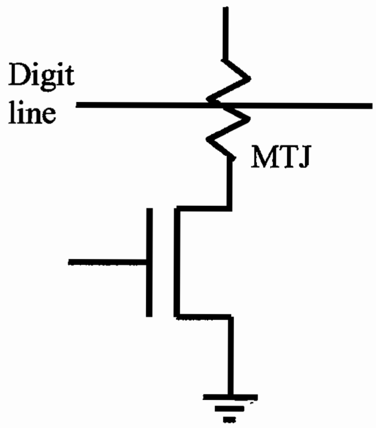

Fig. 4

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