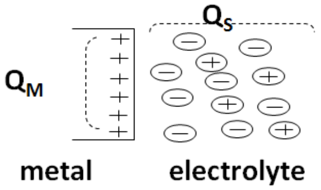
4B6 Crib 2015

Q1

(a) An electrical double layer exists on the interface between and electrode and its surrounding electrolyte. This double layer is formed as ions from the solution adsorbs on the electrode surface. Start from an ideal case: a planar metal electrode in contact with an electrolyte with no chemical reactions occurring between the electrolyte and the metal:



charge neutrality requires:

$Q_M = -Q_S$

The resulting charge distribution – two regions of equal and opposite charge – is known as the electrical double layer and it can be viewed as a capacitor. The double layer capacitance depends on the electrolyte ionic strength and the applied potential if a voltage is applied to the metal. Three models are frequently used to describe the metal/electrolyte interface: Helmholtz model, Gouy-Chapman model and Gouy-Chapman-Stern model. [25%]

(b) (i)

$$K_b = \frac{[SiOH_2^+]}{[H_S^+][SiOH]} \qquad K_a = \frac{[H_S^+][SiO^-]}{[SiOH]}$$

[15%]

(ii)

$$\frac{K_a}{K_b} = \frac{[H_S^+]^2[SiO^-]}{[SiOH_2^+]} \qquad \therefore [H_S^+] = \sqrt{\frac{K_a}{K_b}\frac{[SiOH_2^+]}{[SiO^-]}}$$

[25%]

(iii)

$$-\ln[H_b^+] + \ln\left(\frac{K_a}{K_b}\right)^{\frac{1}{2}} = -\frac{q\Psi_L}{kT} + \underbrace{\ln\left(\frac{[SiO^-]}{[SiOH_2^+]}\right)^{\frac{1}{2}}}_{\text{negligible}}$$

$$-\ln[H_b^+] + \ln\left(\frac{K_a}{K_b}\right)^{\frac{1}{2}} \approx -\frac{q\Psi_L}{kT}$$

[35%]

Q1 Chemical sensor

Least popular question but well-answered by three of the four candidates who took this questions. It is actually a straightforward question.

4B6 Crib 2015

Q2

[10%]

(a) (i) Remnant polarisation: $P_r \sim 25\ \mu C\ cm^{-2}$

(ii) Coercive field: $E_c \sim 80\ kV\ cm^{-1}$ [10%]

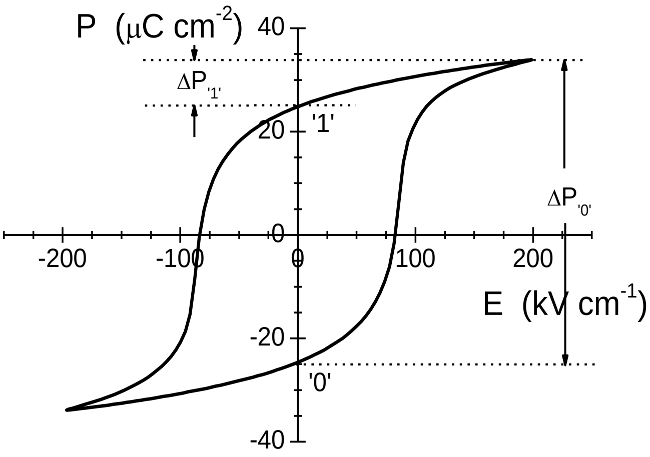
(iii) Energy density consumed in a full switching cycle:

$$E \sim 2Pr*2Ec \sim 8\ J\ cm^{-3} = 8x10^{6}\ J\ m^{-3}$$ [10%]

(b) (i) $\Delta Q = \Delta P*Area = (0.18\mu m*0.18\mu m)\ \Delta P = 3.24x10^{-10}\ cm^{2} *\Delta P$

$\Delta Q_{'1'} = 3.24x10^{-10}\ cm^{2} * \Delta P_{'1'}$
$= 3.24x10^{-10}\ cm^{2} *(34-25)\ \mu C\ cm^{-2}$
$= 2.9x10^{-15}\ C = 2.9\ fC$

$\Delta Q_{'0'} = 3.24x10^{-10}\ cm^{2} * \Delta P_{'0'}$
$= 3.24x10^{-10}\ cm^{2} *(34+25)\ \mu C\ cm^{-2}$
$= 19x10^{-15}\ C = 19\ fC$



[20%]

(ii) $V_{sense} = \Delta Q / C_{sense}$

$V_{sense,'1'} = \Delta Q_{'1'} / C_{sense} = 2.9\ fC / 2\ pF = 1.5\ mV$

$V_{sense,'0'} = \Delta Q_{'0'} / C_{sense} = 19\ fC / 2\ pF = 9.5\ mV$ [20%]

(iii) $\min(\text{Area}) = \min(V_{sense}) * C_{sense} / \max(\Delta P)$

$= 1\text{mV}*2\text{pF}/[(34+25)\mu\text{C cm}^{-2}]$

$= 2\times10^{-15}/59\times10^{-6}\text{ cm}^2 = 3.38\times10^{-11}\text{ cm}^2$

$= 3.38\times10^{-3}\ \mu\text{m}^2$

= 58nm x 58 nm [10%]

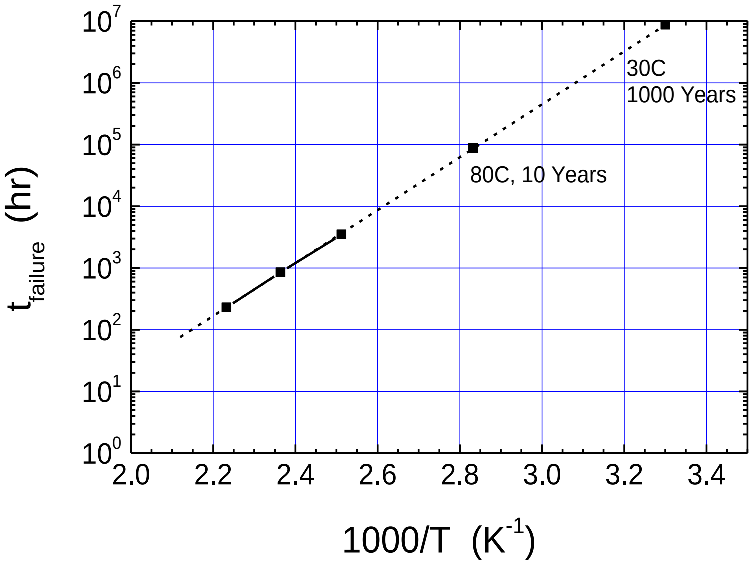
(c) 80ºC → 1000/T = 1000/(80+273) = 2.83 (K^{-1})

30ºC → 1000/T = 1000/(30+273) = 3.30 (K^{-1})

Assuming lifetime $t_{failure} \sim \exp(\Delta E/kT)$, linear extrapolation of the data on the plot gives:

9×10^4 hrs = $9\times10^4/(24*365)$ yrs = 10.27 yrs ~ 10 yrs

9×10^6 hrs = $9\times10^6/(24*365)$ yrs = 1027 yrs ~ 1,000 yrs



[20%]

Q2 FRAM

Most popular question and well answered by many candidates. The loss of marks appears to be largely due to a lack of attention to the details.

Q3

(a) (i) A magnetic tunnel junction (MTJ) consists of two conductive magnetic layers (Co layers here) with a thin non-conductive non-magnetic tunnel layer (Al_2O_3 layer here) in between. The magnetisation is usually switchable only in one layer.

CPP configuration:	Apply voltage across the two conductive magnetic layers and measure the resulting current which tunnels through the non-conductive layer;
CIP configuration:	Apply voltage on the same conductive magnetic layer and measure the resulting current which contains the contribution of electrons tunnelling through the non-conductive layer.

[20%]

(ii) The lower Co layer in the CIP configuration can have effect on the measured current. This is because the non-conductive tunnel layer is thin, in comparison to the de Broglie wavelength of the electron. The spin polarisation state of the electrons flow from one electrode to the other can be altered when they are scattered of from the lower Co layer during transportation, resulting a change in scattering coefficient (depending on the magnetisation direction in the lower Co layer) when they return to the upper Co layer, hence the change in the magnitude of the measured current. Note that this is a pure quantum effect without classical correspondence. [20%]

(iii) A bit of information is physically stored in terms of the direction of magnetisations in the upper and lower Co layers. For example, the parallel (anti-parallel) configuration can be referred as State “1” (State “0”).

The magneto-resistance in a MTJ (in either the CPP or the CIP configuration) is low (high) when the magnetisation directions in the two magnetic layers are parallel (anti-parallel). Therefore, the stored bit of information can be represented by the two levels of MTJ resistance. [10%]

(b) (i) To write a bit of information is to switch the magnetisation in one of the magnetic layers (the upper one here) to the desired direction and leave the magnetisation in the other magnetic layer unchanged, forming a parallel or anti-parallel configuration.

To avoid switching the half-selected cells, switching is performed by using a combined magnetic field induced by the electric current in the corresponding D-Line and B-Line (neither of them can do the switching on its own as shown on the right in Figure 4).

In the case of writing into B2-W2, using D2 to induce a magnetic field and switching the magnetisation half way and followed by using B2 to induce a separated magnetic field in the desired direction to complete the switching. [30%]

(ii) Select W2 to High (i.e. the transistor to ON state), apply a voltage on B2 and measure the current through it. The current level corresponds to the resistance of the MTJ at B2-W2, hence the bit of information stored in it. [10%]

(iii) A MTJ should be rectangle in shape, so that the magnetisation in the switchable layer only has two easy directions, representing the state of stored binary information. [10%]

Q3 MRAM

Joint second popular question. Many of the candidates did well. Most answers are descriptive and conceptual. It appears not easy to cover all the points to get a perfect answer.

Q4

(a)

the threshold voltage corresponds to the condition (for a p-type semiconductor

n (at the surface) = $n_S = N_A$

$n_S = n_0 \exp\left(\frac{q\psi_S}{kT}\right)$, n_0 = conc. of electrons in the bulk

$$n_0 \simeq \frac{n_i^2}{N_A}$$

at threshold:

$$N_A^2 = n_i^2 \exp\left(\frac{q\psi_S}{kT}\right) \qquad \psi_S = 2\frac{kT}{q} \ln \frac{N_A}{n_i}$$

the threshold voltage is the voltage V_G to be applied to the gate to achieve the above surface potential ψ_S

[20%]

(b)

$$V_G = V_i + \psi_S \qquad \psi_S = 0.612 \text{ V}$$

$$V_i = -\frac{Q_S}{C_{ox}} = -\frac{Q_B}{C_{ox}} = \frac{d}{\epsilon_i}\left(2q\epsilon_S N_A\right)^{1/2} = 1.177\text{V}$$

$$V_G \simeq 1.7897 \text{ V}$$

[20%]

(c)

In this case the additional charge of the interface states Q_{it} must be included:

$$Q_{it} = -\int_{E_V}^{E_C} q D_{it} F(E)\, dE = -q D_{it}(E_{F_S} - E_V)$$

where E_{F_S} is the Fermi Level at the surface

$$E_{F_S} - E_V = E_{F(BULK)} - E_V + q\psi_S$$

$$E_{F(BULK)} - E_V \simeq kT \ln \frac{N_V}{N_A}$$

$$Q_{it} = -0.0013 \quad \text{Coulomb } m^{-2}$$

$$V_i = \frac{-Q_{it} - Q_B}{C_{OX}} = 9.16 \quad V$$

$$V_G = 9.77 \quad V$$

[30%]

(d)

The Fermi Function is symmetric about the Fermi Level. So:

$$\int_{E_v}^{E_c} q D_{it} F(E) dE$$

does not change for Dit constant when the correct F(E) is used.

However for any other Dit it will change. In particular if Dit increases exponentially towards the conduction band minimum the difference could be quite substantial

[30%]

Q4 Threshold voltage

Joint second popular question. Again many of the candidates did well. More equations and mathematical calculations than the other ones. Many students can answer large part of it but miss some parts related to physical understanding of the problem by adding together wrong parts or not mentioning the symmetry of Fermi function at the Fermi level.