4B6 Crib 2012

Q1

(a) For a negligible V_{DS}, the threshold voltage V_T is the voltage between gate and source, V_{GS}, such that the concentration of minority carriers at the surface equals the concentration of majority carriers in the bulk. [20%]

(b) In these conditions:

$$|E_F - E_i|_{surface} = |E_F - E_i|_{bulk} = q\psi_B$$

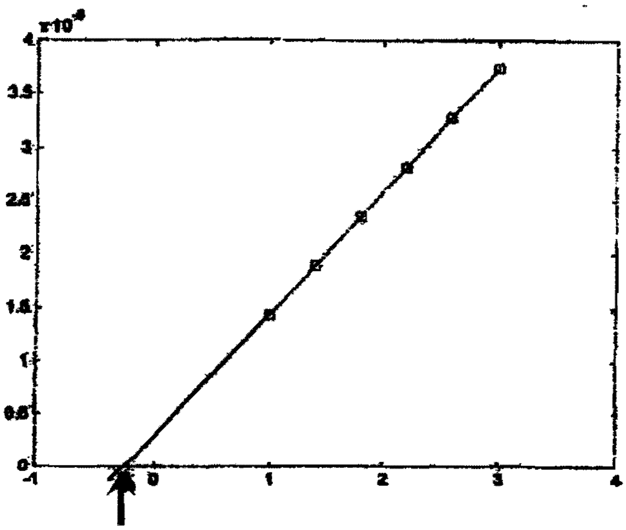
$$N_A \approx p = n_i \exp\frac{q\psi_B}{kT}$$

$$\psi_S = 2\psi_B = \frac{kT}{q}\ln\frac{N_A}{n_i} = 0.618 \text{ V}$$

$$Q_B = -(2\varepsilon_S q N_A \psi_S)^{\frac{1}{2}} = -1.44\times10^{-4} \text{ C m}^{-2}$$

$$V_T = \psi_S + \frac{d}{\varepsilon_i}|Q_B| = 0.659 \text{ V}$$ [40%]

(c)

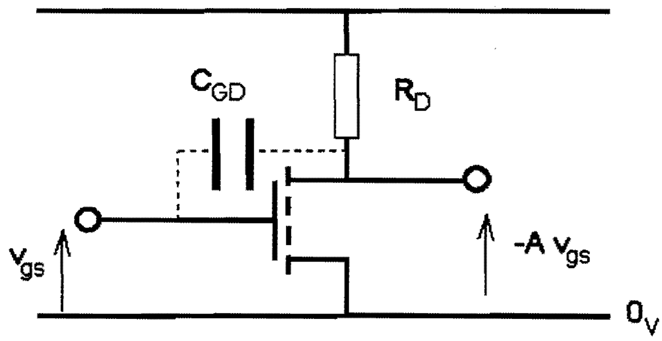


$$V_T = -0.245 \text{ V}$$

$$Q_F = \frac{\varepsilon_i}{d}\Delta V_T = 3.12\times10^{-3} \text{ C m}^{-2}$$ [40%]

Q2

(a)



The Miller effect related to a MOSFET inverting voltage amplifier is associated to the increase in the effective input capacitance due to the amplification of the coupling capacitance between the input and output terminals, such as the gate and drain of the MOSFET. [30%]

(b) For an inverting amplifier with gain A and Miller capacitance C_{GD}:

(i) the input current due to the Miller capacitance C_{GD} is:

$$i_{in} = v_{gs}\,(1+A)\,j\,\omega\,C_{GD}$$ [10%]

(ii) the effective input capacitance is:

$$C_{eff} = C_{GS} + (1+A)\,C_{GD}$$ [10%]

(iii) the upper 3dB frequency is $f_{upper} \propto 1/C_{input}$, therefore:

$$\frac{f_{upper,with}}{f_{upper,without}} = \frac{C_{GS}}{C_{GS} + (1+A)\,C_{GD}}$$ [20%]

(c) Increase of the effective capacitance at the input can lower the bandwidth of the amplifier, reducing its range of operation to lower frequencies.

The physical origin of Miller capacitance here is the overlap of the gate and drain of the MOSFET. Careful design of the device geometry and control of fabrication process will be able to reduce the Miller capacitance significantly. [30%]

Q3

(a) WRITE : WL set to High (i.e. the transistor to ON state);
Apply a positive(negative) voltage pulse betweer l the CP, which is sufficiently high to switch the ferroelectric material of the ferroelectric capacitor to a positive(negative) polarisation direction, corresponding to the "1"("0") state;
WL set to Low (i.e. the transistor to OFF state).

READ : WL set to High (i.e. the transistor to ON state);
Apply a voltage pulse of a fixed polarity (either positive or negative) between the BL and the CP;
Use sense amplifier connected to the BL to detect its potential change and determine the value of the ; (The fixed voltage pulse will switch or not switch the polarisation in the ferroelectric capacitor, depending the information state stored in it and resulting a difference in the amount charge dumped from the capacitor to the BL. ... ...e BL has a finite parasitic capacitance, the difference in the amount of charge translates to the different in the BL potential, which is picked up by the sense amplifier attached to it.)
If the voltage pulse has switched the ferroelectric material, applying a voltage pulse of opposite polarity to switch the polarisation back and restore the originally state of stored information;
WL set to Low (i.e. the transistor to OFF state). [50%]

(b) (i) Remnant polarisation: $P_r = 23\ \mu C\ cm^{-2}$
Coercive field: $E_c = 150\ kV\ cm^{-1}$

(ii) The corresponding electric field for +5V is +500 kV cm^{-2} (= +5V / 100nm).

Resulting charge is:

$\Delta Q = \Delta P$*Area = (0.25μm*0.25μm) ΔP = 6.25x1(?

For State "1" (positively polarised) with CP=+5V and BL=0V,

$\Delta Q_{\text{"1"}} = 6.25\times10^{-10}\ cm^2 * \Delta P_{\text{"1"}} = 6.25\times10^{-10}\ cm^2 * (38+23)\ \mu C\ cm^{-2}$
$= 38\times10^{-15}\ C = 38\ fC$

For State "0" (negatively polarised) with CP=+5V and BL=0V,

$\Delta Q_{\text{"0"}} = 6.25\text{x}10^{-10}\ \text{cm}^2 * \Delta P_{\text{"0"}} = 6.25\text{x}10^{-10}\ \text{cm}^2 * (38\text{-}23)\ \mu\text{C cm}^{-2}$
$= 9.4\text{x}10^{-15}\ \text{C} = 9.4\ \text{fC}$

(iii) Energy consumed due to switching of polarisation from negative to positive direction can be approximated in the order of:

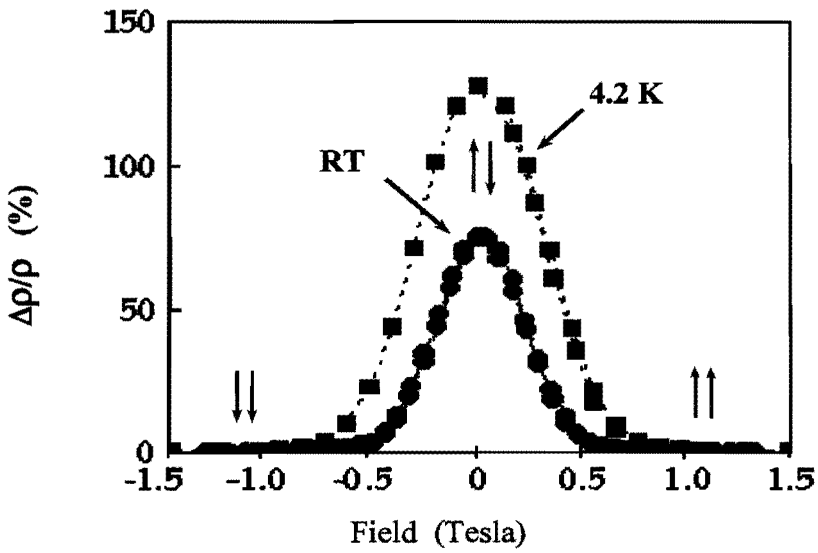
$\Delta E \sim 2*Pr*Ec*Volume = 2*Pr*Ec*Area*Thickness$
$= 2*23\ \mu\text{C cm}^{-2} * 150\ \text{kV cm}^{-1} * 6.25\text{x}10^{-10}\ \text{cm}^2 * 100\text{x}10^{-7}\ \text{cm}$
$= 4\text{x}10^{-14}\ \text{J} = 40\ \text{fJ}$

[50%]

Q4

(a) GMR effect is the phenomena that the magneto-resistance of a system can normally vary more than 50% in an external magnetic field. It is the result of significant spin-related scattering. A GMR unit consists of three basic elements: two metallic FM layers and a non-magnetic layer sandwiched in between. In a metallic FM layer, majority of the spins of the conduction electrons is aligned in the same direction of its magnetisation. As the electrons flow from one FM layer to the other one, they experience different degrees of scattering, depending on the configuration of magnetisation. Such a spin-related scattering, hence the resistance, is maximum/minimum when the directions of magnetisation are parallel/anti-parallel in the two FM layers. The non-magnetic layer, known as spacer, is used to ensure the initial magnetisation in the FM layers is anti-parallel. (30%)

(b) The magnetisation in the FM layers is anti-parallel when the external magnetic field is zero. The $\Delta\rho/\rho$ reaches its maximum value in this situation. As the strength of the external field increases, the magnetisation opposite to the external field is reduced, hence the $\Delta\rho/\rho$. When the magnetisation of the FM layers is nearly parallel, the $\Delta\rho/\rho$ approaches its minimum. The maximum $\Delta\rho/\rho$ shall increase when the temperature is reduced from room temperature (RT) to 4.2K because of the higher degree anti-parallel alignment at the low temperature. The symmetric behaviour of the $\Delta\rho/\rho$ for the positive and negative external magnetic field is due to equivalence of the system when fully magnetised in the opposite directions. (40%)



The magneto-resistance MR% is defined as:

$$\text{MR\%} = \frac{R(\text{AP}) - R(\text{P})}{R(\text{P})} \times 100 = \frac{\Delta R}{R}(\%) = \frac{\Delta \rho}{\rho}(\%)$$

where R(AP) and R(P) are the resistance at parallel and anti-parallel situations, respectively. Since R(AP) is always larger than R(P), the MR% can be more than 100% if R(AP)>2*R(P).

(c) PSV consists of two FM layers: one "soft" layer and one "hard" layer. The direction of magnetisation in the hard layer is more difficult to switch than in the soft layer, and it is used to represents the information stored in the cell. The Write is achieved by magnetising the hard layer in the desired direction. To avoid the mis-write due to the half-selection, we need to go through two steps: (a) send a current pulse to the word line, switching the magnetisation nearly half way in all the half-selected cells; (b) send another current pulse of either positive or negative sign to the bit line to finally switch the selected cell to the desired direction. Only the combined field is strong enough to switch the hard layer of the selected cell, while the half-selected cells remain unchanged. (30%)