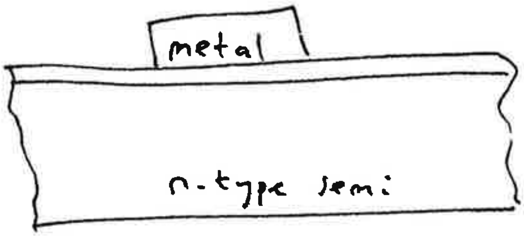
4B6

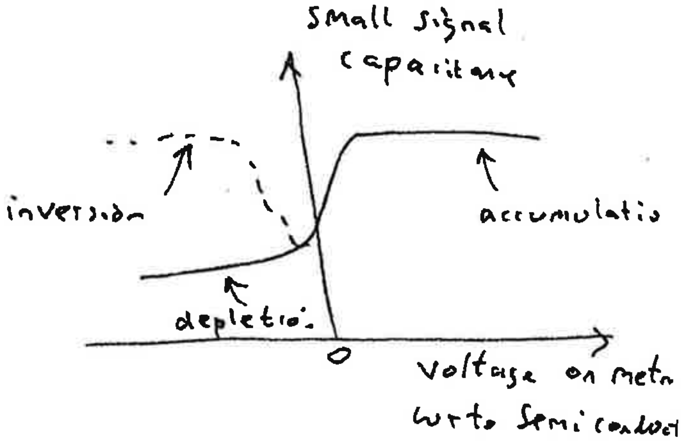
Example Paper 2

Q 1

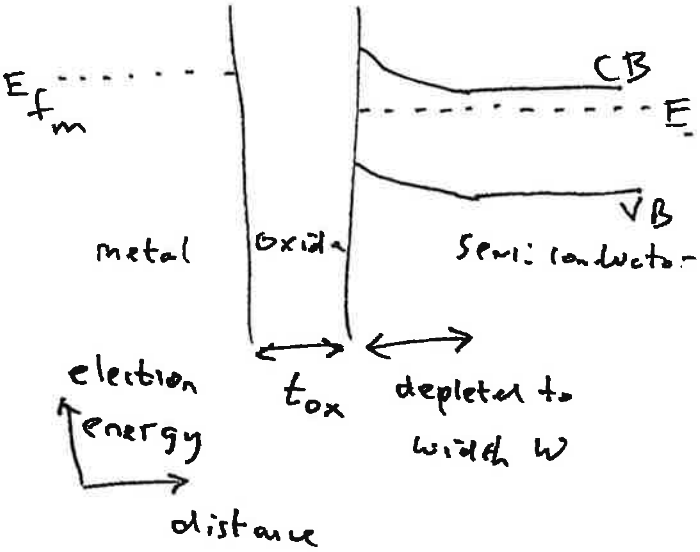
(a) measuring the capacitance between the metal and the substrate reveals when the semiconductor is depleted



because the capacitor plate separation effectively becomes $t_{ox} + W$ and the capacitance is smaller than in the accumulation case.



the maximum extent of the depletion region is determined by the doping density and the semiconductor bandgap

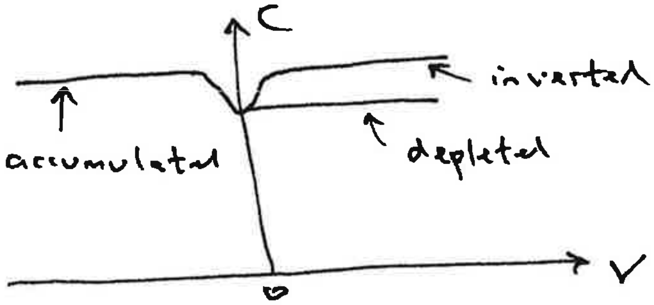


small signal rather than large signal is useful to probe the doping profile as the semiconductor is progressively depleted upon decreasing the bias voltage

at high measurement frequency and in the absence of light the semiconductor can be biased into deep depletion and this non equilibrium state probed by avoiding inversion.

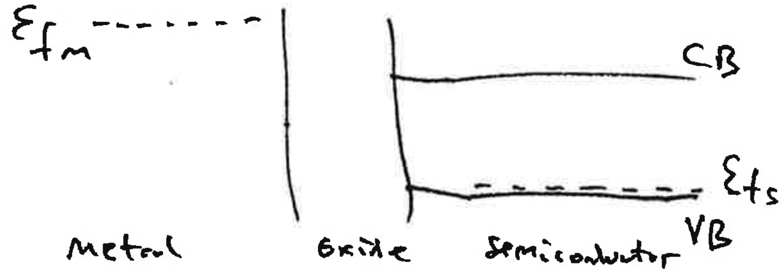
(b)

In the p-type semiconductor case inversion occurs for positive bias.



For highly doped material the extent of the depleted region is limited and the modulation of the capacitance is small.

The extent of the band bending is small in the accumulation case because a small change results in a large hole concentration at the interface.



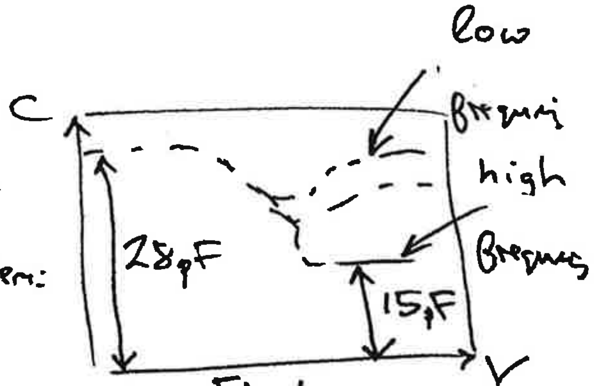


Fig 1

(c) two capacitors: $\frac{1}{C_{total}} = \frac{1}{C_{oxide}} + \frac{1}{C_{semi}}$

$$\frac{1}{C_{min}} = \frac{d_{ox}}{\varepsilon_{ox} A} + \frac{W}{\varepsilon_{se} A}$$

$$\frac{1}{C_{max}} = \frac{d_{ox}}{\varepsilon_{ox} A}$$

$$\therefore \quad W = \varepsilon_{se} A \left(\frac{1}{C_{min}} - \frac{1}{C_{max}} \right)$$

$$= d_{ox} C_{max} \frac{\varepsilon_{se}}{\varepsilon_{ox}} \left(\frac{1}{C_{min}} - \frac{1}{C_{max}} \right)$$

max. extent $W = d_{ox} \frac{\varepsilon_{se}}{\varepsilon_{ox}} \left(\frac{C_{max}}{C_{min}} - 1 \right)$

$$= 100 \times \frac{10}{4} \left(\frac{28}{15} - 1 \right) = 217 \text{ nm}$$

It is a lower limit but a small minimum capacitance may have been obtained with an even higher measurement frequency.

Q.2

In this case E_i and E_F are not given, but we can express ψ_B in terms of N_A:

$$\psi_B = \frac{E_i - E_F}{q}$$

$$n_i = N_V \exp\left(\frac{E_V - E_i}{kT}\right) \qquad (1)$$

$\nearrow$ intrinsic carrier concentration)

$$N_A = N_V \exp\left(\frac{E_V - E_F}{kT}\right) \qquad (2)$$

Dividing (2) by (1)

$$q\psi_B = E_i - E_F = kT \ln\left(\frac{N_A}{n_i}\right) \qquad (3)$$

$$\psi_B = 0.298 \text{ V}$$

In strong inversion:

$$Q_B = -\left[2\epsilon_s q N_A (2\psi_B + V_c)\right]^{1/2}$$

where V_c is the channel potential.

At the source $V_c = 0$

$$Q_B = -1.42 \times 10^{-8} \text{ Coulom cm}^{-2}$$

and the depletion length

$$X_d = -\frac{Q_B}{q N_A} = 0.886 \, \mu m$$

At the drain $V_c = 5$ V

$$Q_B = -4.34 \times 10^{-8} \text{ Coulom cm}^{-2}$$

$$X_d = 2.71 \, \mu m$$

Q.3

The drift velocity is given by:

$$v_D = \mu_n E_y$$

where $E_y = \frac{dV_c}{dy}$ is the horizontal componen of the electric field in the channel. So

$$E_{y\,max} = \frac{v_{D\,max}}{\mu_n} = \frac{10^6}{1000} = 10^3\ V\,cm^{-1}$$

From equation 3 of Q.3 we have:

$$\psi_B = \frac{kT}{q} \ln\left(\frac{N_A}{n_i}\right) = 0.298\ V$$

The threshold voltage:

$$V_T = 2\psi_B + \left[2\epsilon_s q N_A (2\psi_B)\right]^{1/2} \frac{d}{\epsilon_i} = 0.72V$$

Since

$$V_G - V_{DS} \gg V_T$$

there is inversion at every point in the channel.

Comment:

Rigorously, to prove that inversion occurs everywhere, we need to prove That the conductance G is > 0 everywhere For this is sufficient That G is > 0 at the drain. See equations 1 and 2 below.

In strong inversion, the conductance G is given by:

$$G = \mu_n \frac{\epsilon_i}{d}\left[V_{GS} - \left(2\psi_B + V_C - \frac{d}{\epsilon_i} Q_B\right)\right] \quad (1)$$

where

$$Q_B = \left[2\epsilon_s q N_A (2\psi_B + V_C)\right]^{1/2} \quad (2)$$

The current:

$$I_d = W E_y G(y)$$

Since I_d is constant, the maximum value of the horizontal field E_y occurs where $G(y)$ is minimum, that is at the drain. The value of G at the drain is obtained by setting $V_C = V_{DS}$ in equations (1) and (2). One has:

$$Q_B = -2.96 \times 10^{-8} \text{ Coulomb cm}^{-2}$$

$$G(\text{at drain}) = 2.47 \times 10^{-4}\ \Omega^{-1}$$

Hence:

$$I_{d\max} = W E_{y\max} G(\text{drain})$$
$$= 2.47 \times 10^{-4} A$$

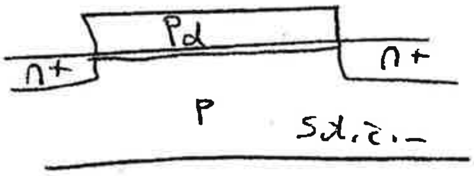
Q. 4

Gap states in amorphous Si (referred to as a-Si or α-Si) and polycrystalline Si (referred to as polysilicon) are due to: 1) Dangling Bonds; 2) Reconstructed or Weak Bonds, that is bonds formed between dangling bonds separated by more than one lattice constant; 3)Disorder Induced Localised States.

Dangling Bonds are due to the presence of Si atoms with co-ordination lower than 4, which leaves one bond uncoordinated. Co-ordinated bonds are directional, uncoordinated ones are not, hence the adjective 'dangling'. These defects are believed to give rise to energy levels near midgap. Some dangling bonds can reconstruct resulting in 'weak' bonds (they are called weak because they stretch over more than a perfect Si-Si tetrahedral bond distance). The energy levels associated with these are believed to span the entire energy gap. Disorder Induced Localised States are due to a quantum mechanical effect: when the disorder-induced fluctuations of the crystal potential exceed a critical value (dependent on the atomic species involved) localized states form. These are located near the conduction and valence band edges.

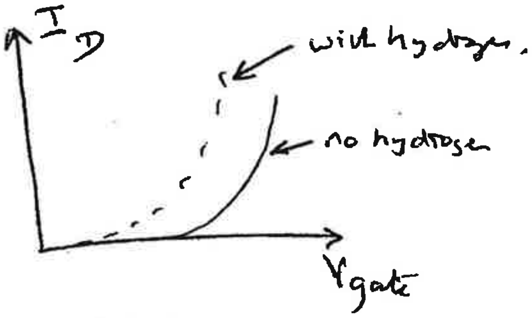
The difference between amorphous and polycrystalline Si is that in the former traps are uniformly distributed whereas in the latter they are concentrated at grain boundaries,

Q. 5

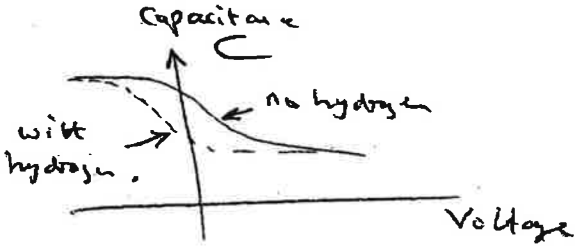


CROSS SECTION

On a metal oxide semiconductor structure is sensitive to hydrogen because it can diffuse into the electrode and change the threshold by changing the metal workfunction.



Other gases which can be detected using this principle include H_2S, NH_3, CO etc.



The hydrogen is adsorbed at the interface and generates a +ve charge resulting in the formation of a dipole layer.

b) Hydrogen ion concentration is expressed in terms of pH on a log scale of moles per litre (1 mole is 6×10^{23} ions)

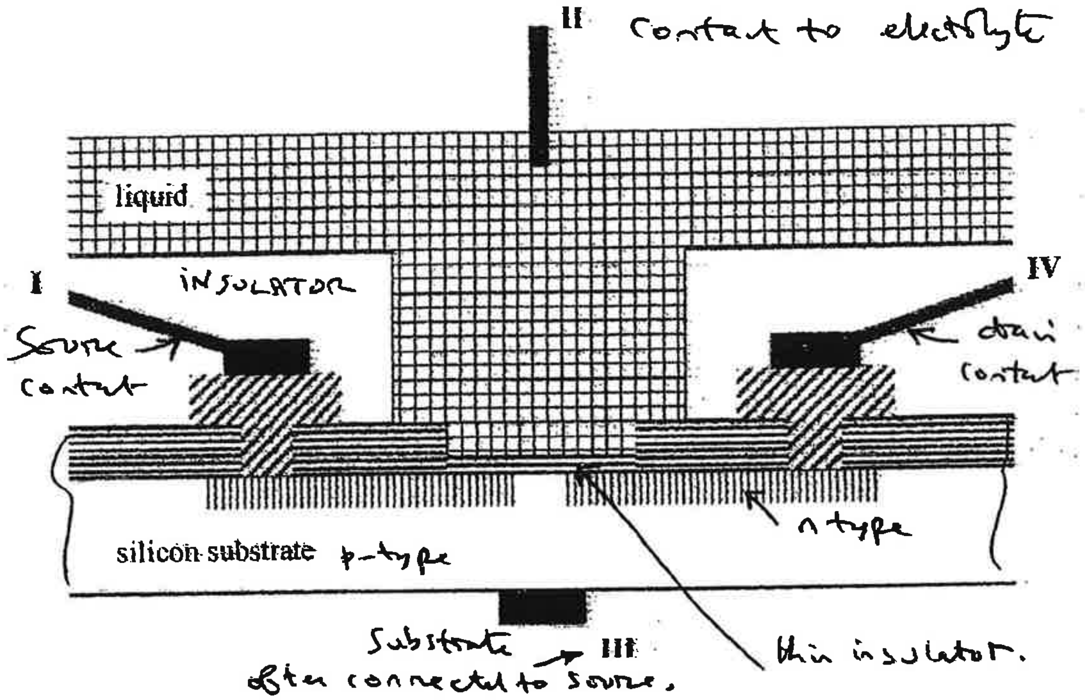
$$pH = -\log_{10}[H^+]$$

$pH \lesssim 7$ acidic
$pH \gtrsim 7$ basic solution

In a biosensor a bioreceptor is immobilized on the surface of a compatible transducer

eg. glucose oxidase promotes the reaction of glucose with oxygen, one of the byproducts is hydrogen peroxide and gluconic acid is also formed → pH change.

4B6 Q5 (continued)
ISFET structure

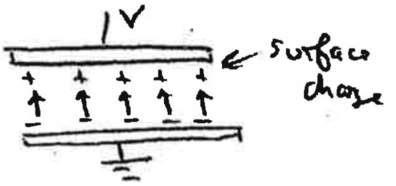


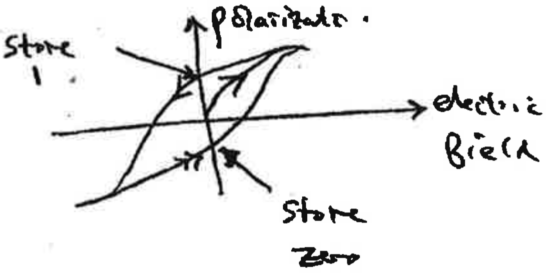
The ISFET serves to sense and amplify changes in the double layer potential due to changes in the pH of the liquid.

By functionalizing the gate insulator ~~surface~~, organic or biological compounds of interest can be detected.

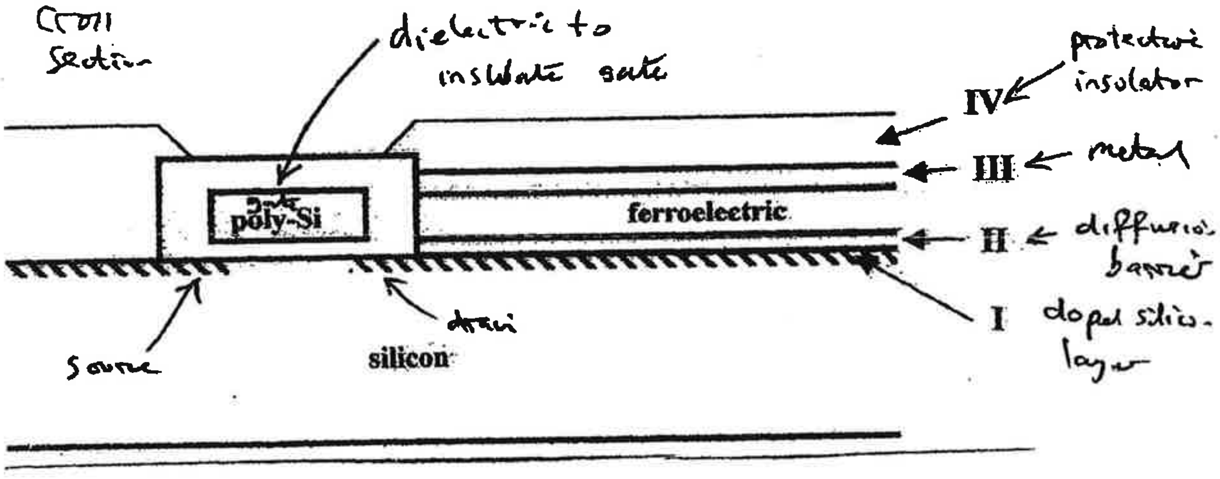
The detection method is usually to monitor the current as a function of time for a given source drain voltage which reflects variations in the threshold (pH)

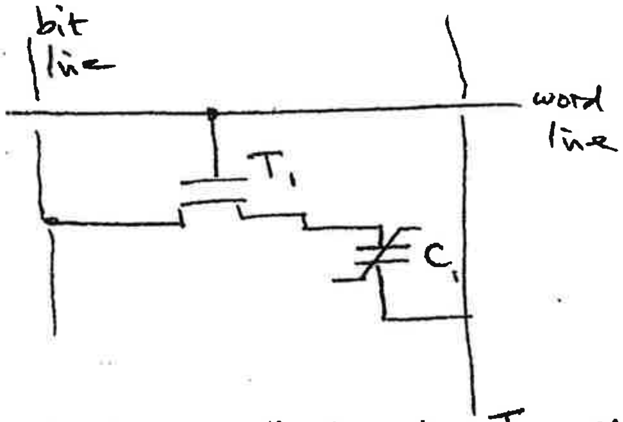
436 Q.6 a) The electric dipoles in ferro electric materials can be aligned to polarize the material by application of an external field. This is the basis of a non-volatile memory device.





b)





data is stored by applying a high positive or negative voltage to polarize the ferro electric.

eg. the word line is high to turn on the transistor T_1 and then a voltage is applied to the bit line to bias the cell C_1

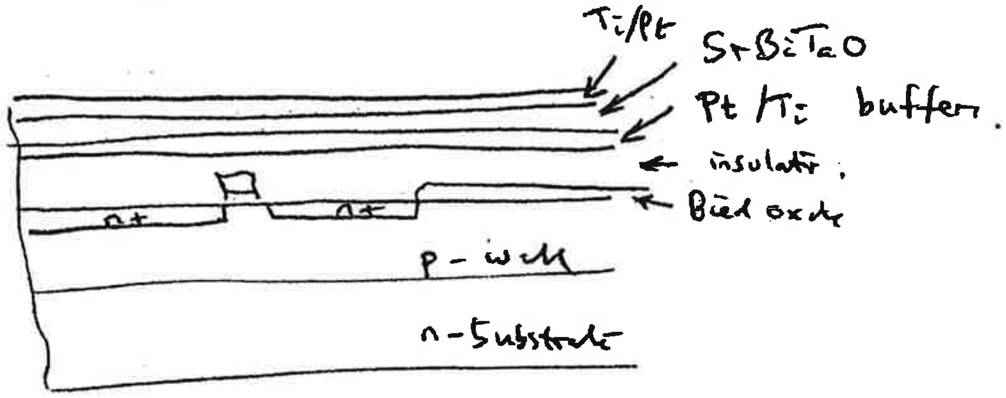
Readout: In the charge approach the cell is addressed and the charge $\Delta Q = A\,\Delta P$ corresponding to a change in polarization is detected.

In the field approach $E \propto P$ and the potential on the device is detected.

4B6 Q.6 (cont'd)

The most critical fabrication steps are the deposition of the ferroelectric layers and the diffusion barrier.

eg. Cross SECTION



Subsequent steps to etch patterns in the ferroelectric layers and make contacts to the source and drain regions are less critical.

c) Ferroelectric memory is becoming widespread for low power portable applications.

In 2003 ferroelectric memory was available with a stacked geometry and 0.18 μm minimum linewidth technology.

The prospects are good for further technology improvements for thinner ferroelectric layers to give lower voltage operation.