MOS Capacitor (15%)

1. Figure 1(a) shows the C-V curve of MOS capacitor with different measurement conditions, and Figure 1(b) shows their equivalent circuits, please answer the following questions,

   1a. In Fig. 1(a), which curve is high frequency CV curve? (a), (b) or (c) (2%)

   1b. In Fig. 1(a), what are the surface potentials (ψ_s) of point A and B? (4%)

   1c. In Fig. 1(b), which case is equivalent to low frequency CV? And why? (3%)

   1d. What is the equivalent circuit of curve (c)? (to re-plot by case B) (3%)

   1e. Figure 1(c) is the inversion electron distribution (Qi) with classical and quantum solutions, explain the difference of inversion capacitance (Ci) for the two kinds of distributions. (3%)

Fig. 1(a)

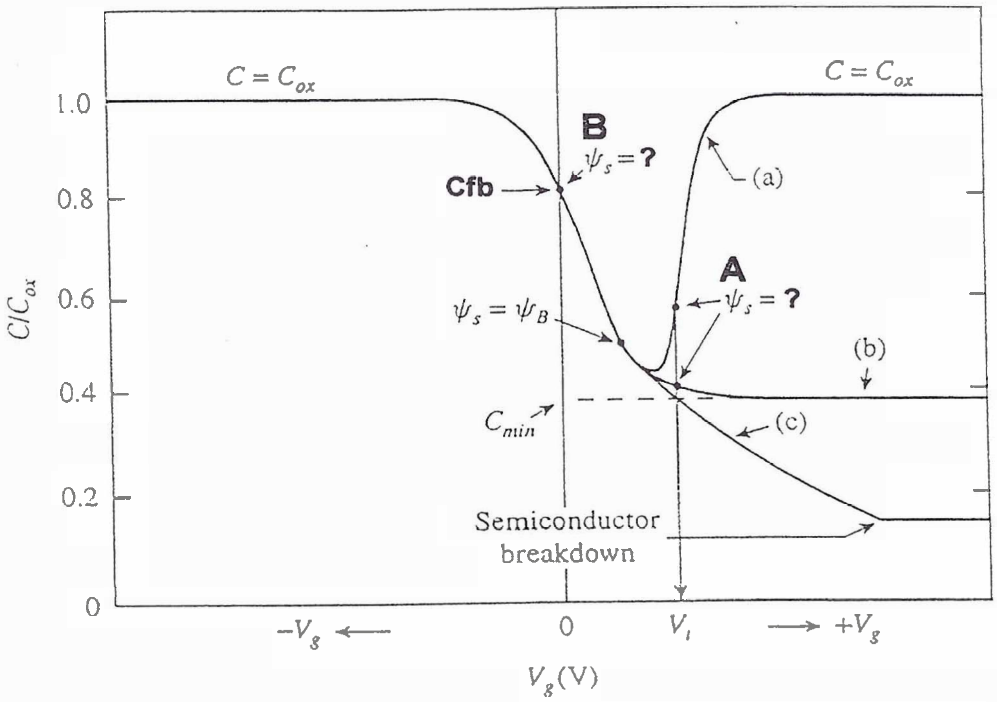


Fig. 1(b)

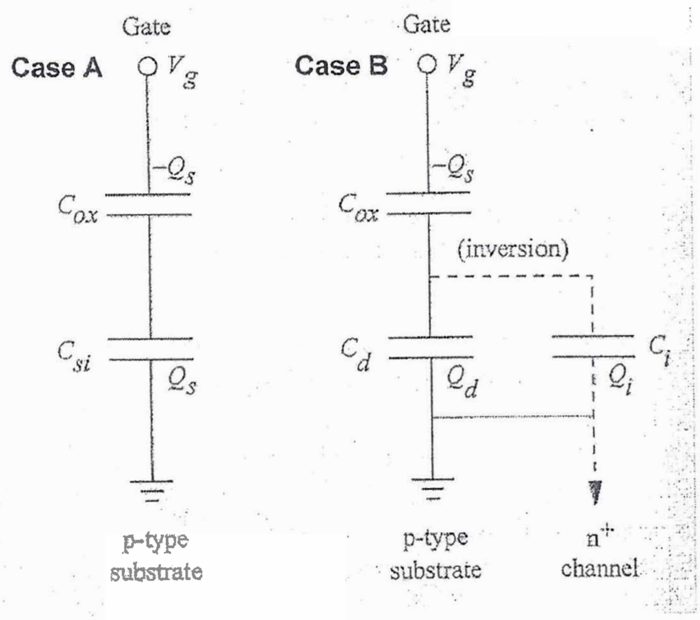
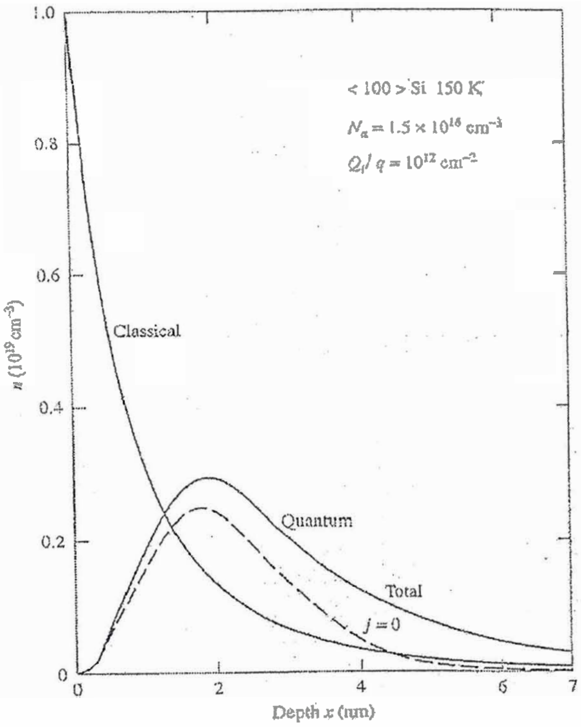

Case A
Gate
V_g
$-Q_s$
C_{ox}
C_{si}
Q_s
p-type substrate
Case B
Gate
V_g
$-Q_s$
C_{ox}
(inversion)
C_d
Q_d
C_i
Q_i
p-type substrate
n^+ channel

Fig. 1(c)


< 100 > Si 150 K
$N_a = 1.5 \times 10^{16}$ cm^{-3}
$Q_i/q = 10^{12}$ cm^{-2}
Classical
Quantum
Total
$j = 0$
n (10^{19} cm^{-3})
Depth x (nm)
1.0
0.8
0.6
0.4
0.2
0
0
2
4
6
7

Charge Control Model (15%)

2. Figure 2 shows a high (Ns) - low (Na) channel doping concentration profile of MOS transistor (Ns an same impurity type), answer the questions below,

2a. assuming the surface potential is ψ_s, what is the depletion width W_d? (10%)

2b. based on the result of 2a, what is the depletion width at threshold? (5%)

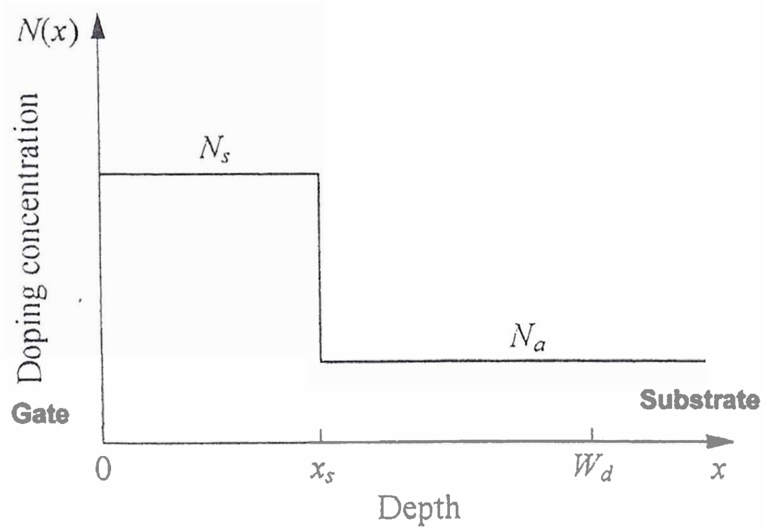
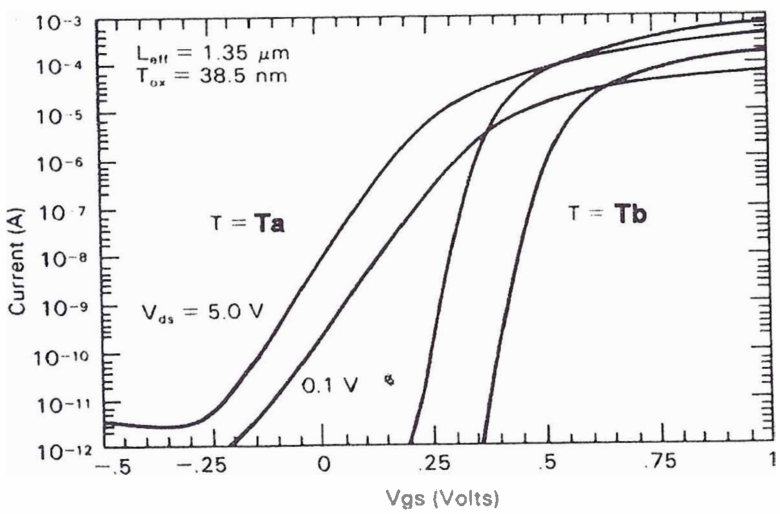


Figure 2

MOS Transistor (5%)

3. Figure 3 shows Id-Vg curves of MOS transistor at high and low temperatures, please answe temperature is higher (Ta or Tb), and explain how to judge (list two differences at least)? (5%)

Figure 3



Bipolar Junction Transistor (35%)

4.(a)Plot the **band diagram** for a PNP bipolar junction transistor with emiter-base junction forward-based and base-collector junction reverse-biased. You must include Ei, intrinsic level and both **quasi-Fermi levels** in your plot. Mark clearly the emitter, base and collector regions in your plot. (5%)

(b)Following (a), plot the **minority carrier profile** in each region for the PNP bipolar junction transistor with emiter-base junction forward-based and base-collector junction reverse-biased. Assumed that the width of base and emitter regions are very small compared to the diffusion lengths of the minority carriers in base and emitter, respectively; and that the width of collector region is much larger than the diffusion length of the minority carriers in collector. (6%)

(c)From the minority carrier profile in (b), write down the **emitter current density, collector current density, and base current density** for the PNP bipolar junction transistor described in (a) and (b). Use $N_E, N_B, N_C, D_E, D_B, D_C$ to denote the doping levels, the diffusion coefficients of minority carriers in emitter, base, and collector, respectively. Use also $W_E, W_B, W_C, L_E, L_B, L_C$ for the width and minority-carrier diffusion length in emitter, base, and collector respectively. You may mark in your plot in (b) the direction of current in each region. You must include the recombination current component in base neutral region. However, generation-recombination currents in depletion region may be omitted. (9%)

(d)Explain the following terms: (1) **emitter efficiency**, (2) **base transport factor**, (3) **base transit time**, (4) **Early effect**, and (5) **Kirk effect**. (15%)

Effective Density of States (10%)

5. The effective density of states N_C and N_V are used to calculate the equilibrium electron and hole concentration in conduction band and valence band, respectively. Explain the physical meaning of these two parameters. (10%)

$$n_o = N_C \exp\left[-(E_C - E_f)/kT\right] \qquad N_C = 2\left(\frac{m_n^* kT}{2\pi \hbar^2}\right)$$

$$p_o = N_v \exp\left[-(E_f - E_v)/kT\right] \qquad N_v = 2\left(\frac{m_p^* kT}{2\pi \hbar^2}\right)$$

Switching Characteristics of a Diode (20%)

6. The input voltage shown below is applied to a diode and a series resistor R_1, explain the reason for the observed diode current (10%) and diode voltage (10%) waveforms.