EE 735: ASSIGNMENT 6

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QUESTION 1

Consider a PN junction as shown in figure 1, $N_A = 10^{17}$ cm^{-3} and $N_D = 10^{17}$ cm^{-3}. Plot the I-V in semi-log scale for the following cases with the voltage ranging from -10 V to 2 V.
Note: For part (a) use only SRH and for part (b) use only band-to-band recombination models.

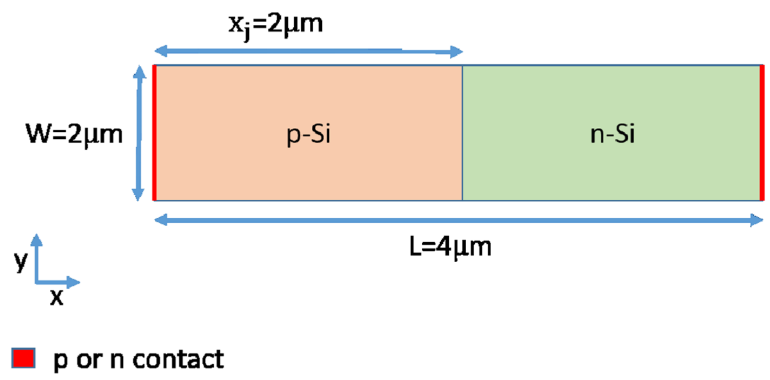


Figure 1

(a) SRH

(a.1) With and without SRH (Shockley-Read-Hall) recombination. Explain the difference in the I-V characteristics (if any).

(a.2) In the “models.par” file, change the value of “taumax” to “1e-7” and “3e-8” for electrons and holes respectively. Explain the changes in the I-V characteristics (semi-log).

(a.3) Repeat (a.2) for “taumax” = “1e-4” and “3e-5” for electrons and holes respectively. Explain the changes in the I-V characteristics (semi-log).

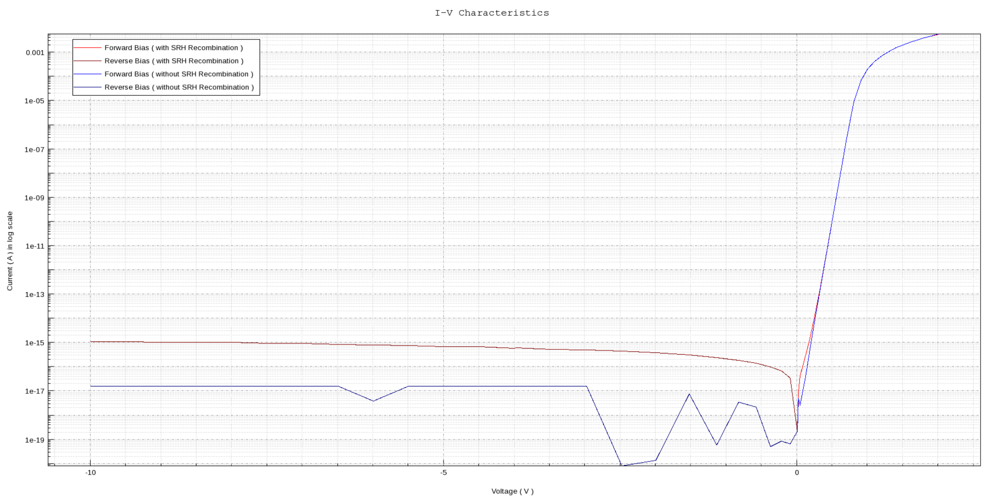
(b) Band-to-band

(b.1) With and without band-to-band recombination (E2 model). Explain the difference in the plots (if any).

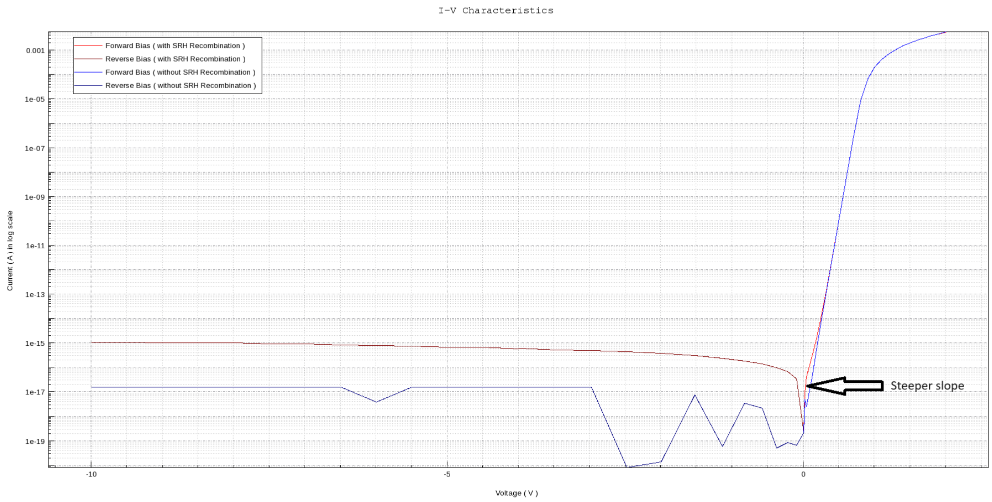
(b.2) For various doping levels of $N_A = N_D = 5 \times 10^{17}$, 10^{18} and 10^{19} cm^{-3} with band-to-band recombination. Explain the trend.

RESULT AND CONCLUSION

The I-V characteristics for (a.1) with and without SRH recombination is given below,

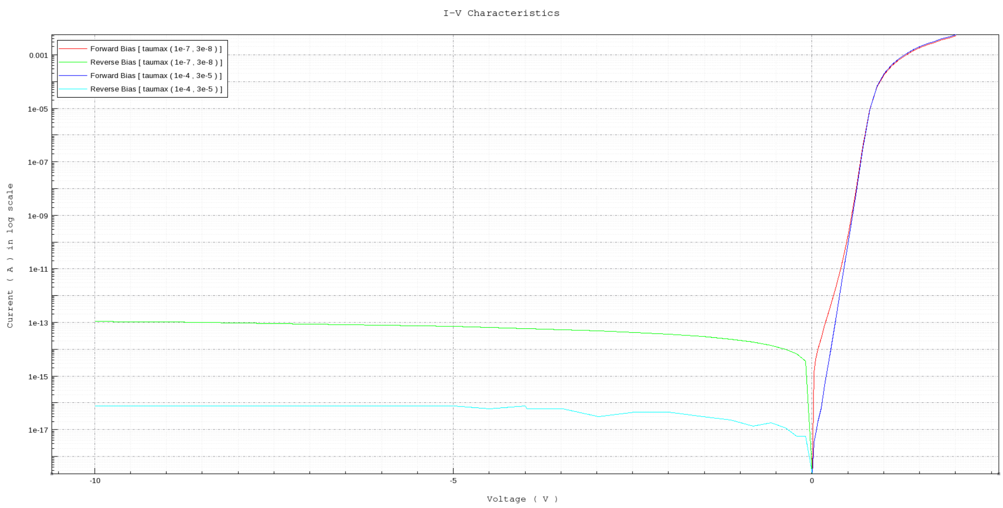


For **forward bias** condition due to SRH recombination the current for low bias voltages increases steeper than the current simulated without SRH recombination as given below,



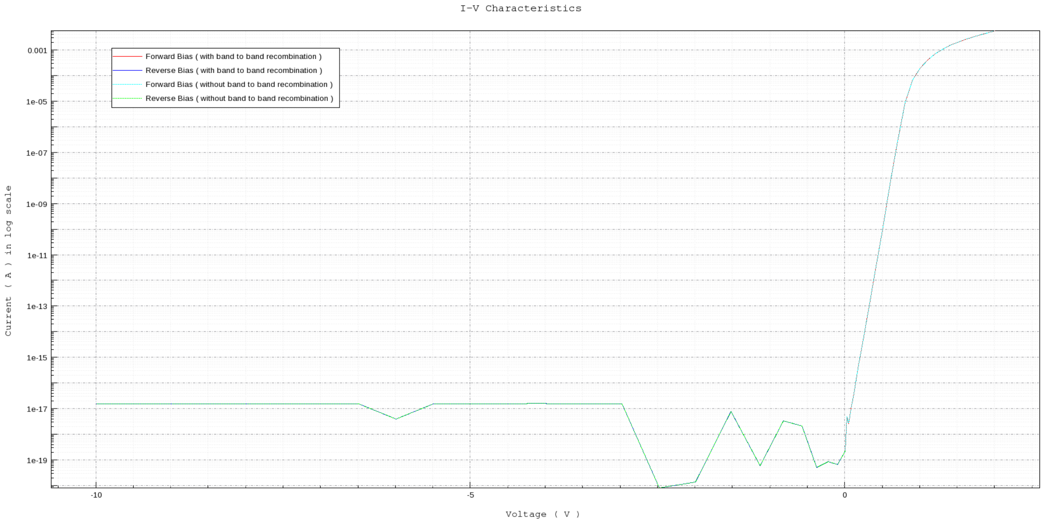
For **reverse bias** condition due to SRH recombination the reverse current is greater than the current simulated without SRH recombination as more electrons and holes are generated via the trap level to re-establish thermal equilibrium which leads to additional generation current in reverse bias.

The I-V characteristics for (a.2) and (a.3) with SRH recombination is given below,



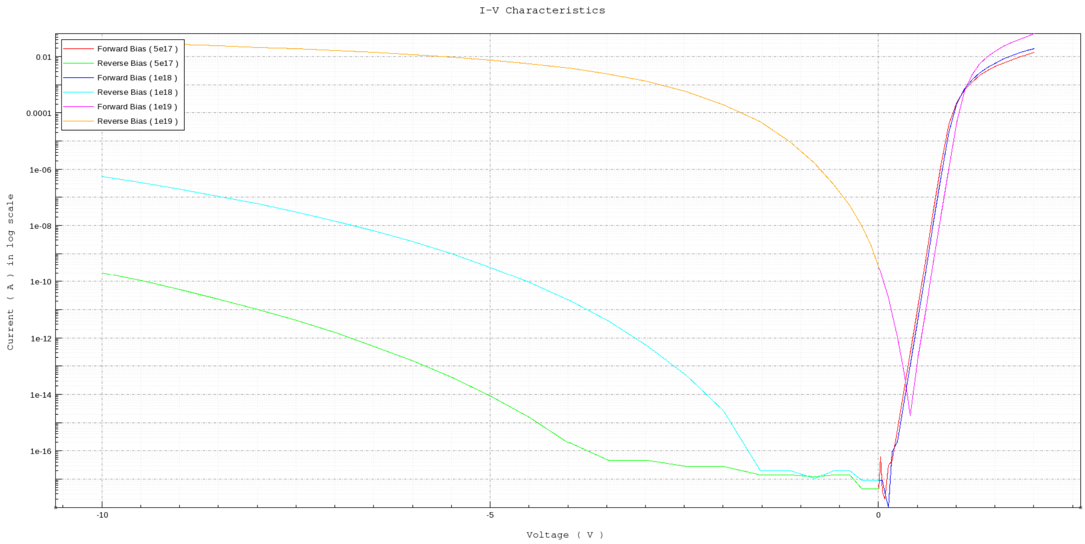
As recombination current is inversely proportional to minority carrier lifetime τ, the reverse bias current and forward bias current for lower bias voltage is higher for lower values of minority carrier lifetime.

The I-V characteristics for (b.1) with and without band-to-band recombination is given below,



Since, Silicon is high band-gap semiconductor so the band-to-band recombination does not play any significant role in current leading to same I-V characteristics for both with and without band-to-band recombination.

The I-V characteristics for (b.2) with band-to-band recombination is given below,



With increase in doping concentration the reverse bias current increases. Due to high doping the semiconductor becomes degenerate semiconductor and it behaves as Zener diode.

QUESTION 2

Simulate and plot the band diagram and charge profiles (electron and hole) of a MOS capacitor (n-MOS) biased at $V_g = V_T$ (inversion region) based on the data given in part (a). Use Al as gate metal. Figure 2 shows the schematic of a typical MOS device. Consider L = W = 1 µm.

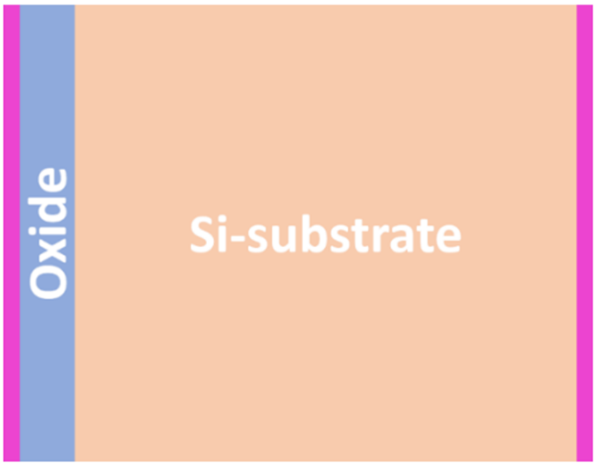


Figure 2: Schematic of a MOS capacitor

(a) Take gate-oxide (SiO_2) thickness t_{ox} = 3 nm and Si substrate doping $N_A = 3\text{x}10^{16}$ cm^{-3}.
(b) Now, change the SiO_2 thickness to 2 nm for the same substrate doping as in part-a.
(c) Consider t_{ox} = 3 nm and change the substrate doping to $N_A = 3 \text{ x } 10^{17}$ cm^{-3}.

Note: Please write your observations on how oxide thickness and substrate doping concentration affect the V_T.

RESULT AND CALCULATION

At threshold the value of surface potential, $\psi_s = 2\phi_{fp}$ where, $\phi_{fp} = V_{th} ln\left(\frac{N_A}{n_i}\right)$

Ignoring trapped oxide charges threshold voltage,

$$V_T = \phi_{ms} + \frac{\sqrt{4qN_A\epsilon_s\phi_{fp}}}{C_{ox}} + 2\phi_{fp}$$

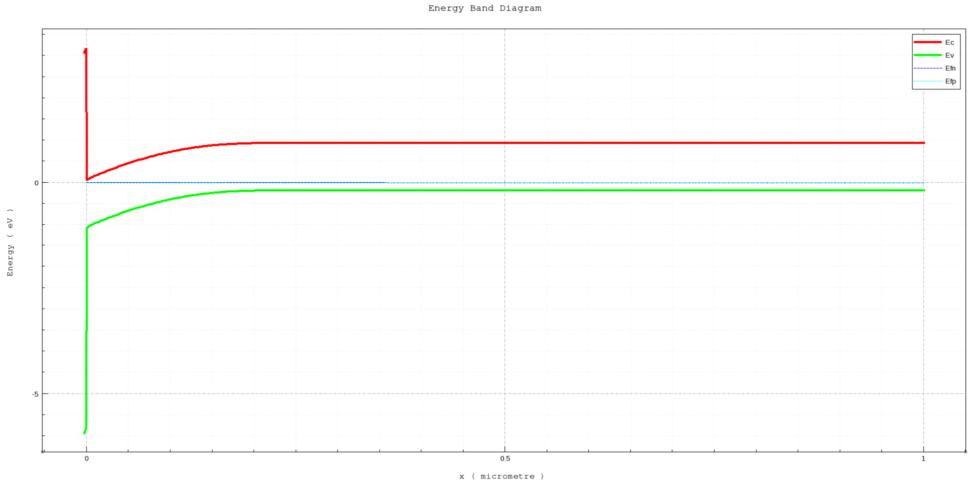
Now, $\phi_{ms} = \phi_m - \phi_s$ where $\phi_m = 4.28\ eV$ and $\phi_s = \chi + \frac{E_g}{2q} + \phi_{fp}$ and

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$

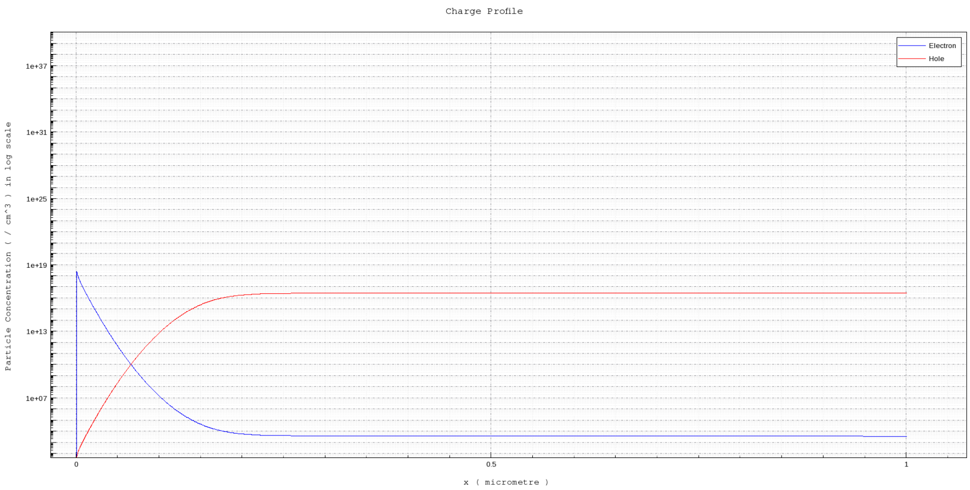
(a) For $V_{th} = 0.026\ V,\ \ \chi = 4.05\ V,\ \ q = 1.6\ \times 10^{-19}\ C,\ \ E_g = 1.12\ eV,\ \ \epsilon_s = 1.0443 \times 10^{-14}\ F/cm,\ \ \epsilon_{ox} = 3.54 \times 10^{-13}\ F/cm,\ \ n_i = 1.5 \times 10^{10}\ /cm^3\ \ N_A = 3 \times 10^{16}\ /cm^3$ and $t_{ox} = 3\ nm$

$V_T = 0.1207\ V$

The plot of the band diagram for $V_g = 0.1207\ V$ is given below,



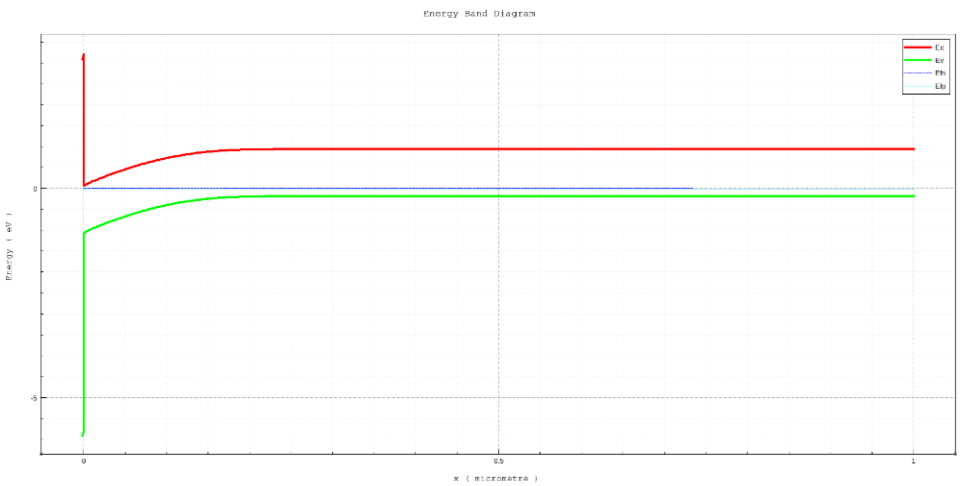
The plot of charge profiles (electron and hole) is given below,



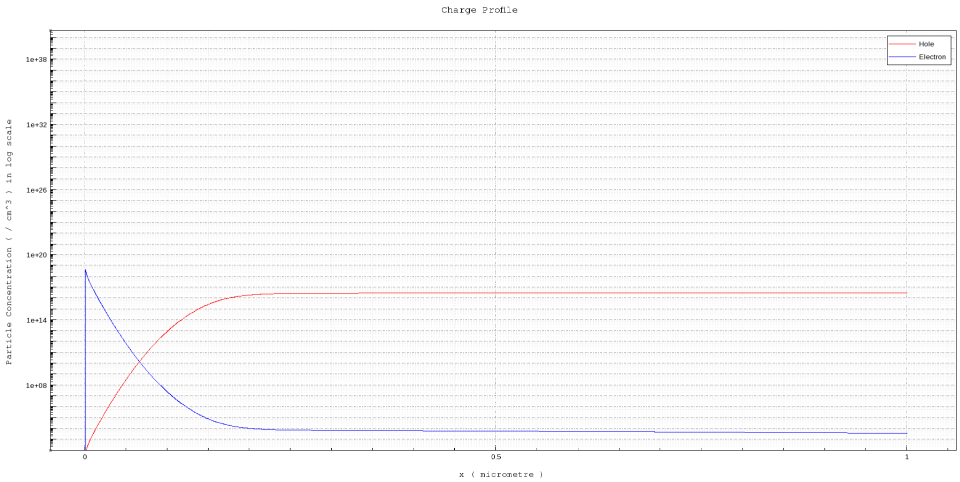
(b) For $V_{th} = 0.026\ V$, $\chi = 4.05\ V$, $q = 1.6\ \times 10^{-19}\ C$, $E_g = 1.12\ eV$, $\epsilon_s = 1.0443 \times 10^{-14}\ F/cm$, $\epsilon_{ox} = 3.54 \times 10^{-13}\ F/cm$, $n_i = 1.5 \times 10^{10}\ /cm^3$ $N_A = 3 \times 10^{16}\ /cm^3$ and $t_{ox} = 2\ nm$

$V_T = 0.0960\ V$

The plot of the band diagram for $V_g = 0.0960\ V$ is given below,



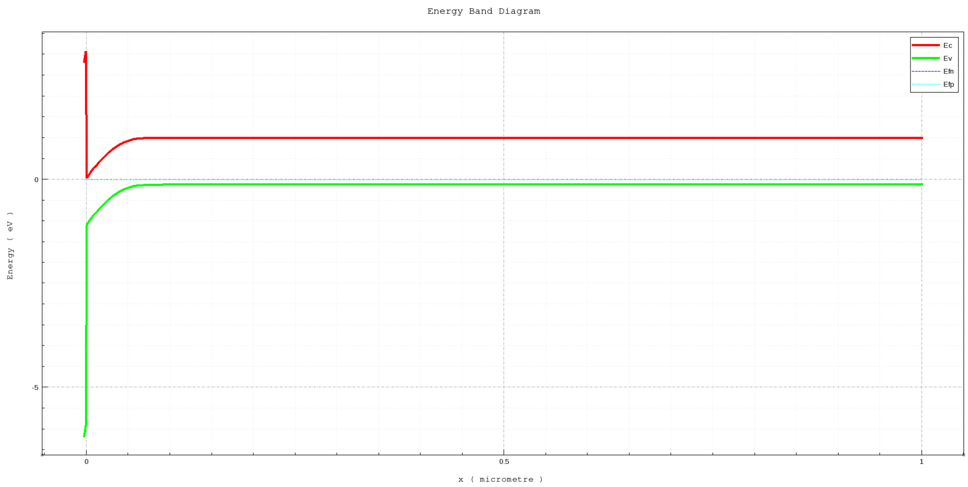
The plot of charge profiles (electron and hole) is given below,



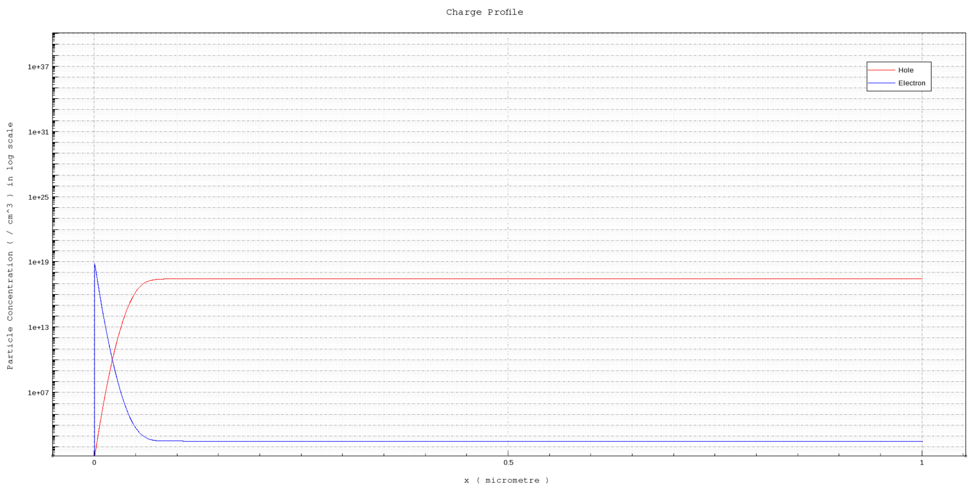
(c) For $V_{th} = 0.026\,V$, $\chi = 4.05\,V$, $q = 1.6 \times 10^{-19}\,C$, $E_g = 1.12\,eV$, $\epsilon_s = 1.0443 \times 10^{-14}\,F/cm$, $\epsilon_{ox} = 3.54 \times 10^{-13}\,F/cm$, $n_i = 1.5 \times 10^{10}\,/cm^3$ $N_A = 3 \times 10^{17}\,/cm^3$ and $t_{ox} = 3\,nm$

$V_T = 0.3578\,V$

The plot of the band diagram for $V_g = 0.3578\,V$ is given below,



The plot of charge profiles (electron and hole) is given below,



OBSERVATION

The threshold voltage V_T depends upon both oxide thickness t_{ox} and substrate doping concentration N_A. With decrease in oxide thickness the oxide capacitance increases and thus the value of threshold voltage decreases and with increase in doping concentration the value of threshold voltage increases.

QUESTION 3

Simulate and plot the C-V (at 100 kHz) of a MOS capacitor (n-MOS) for a voltage range of -5V to 2V. Use substrate doping of 3 x 10^{17} cm^{-3} and Al as gate metal. Consider L = W = 1 μm.

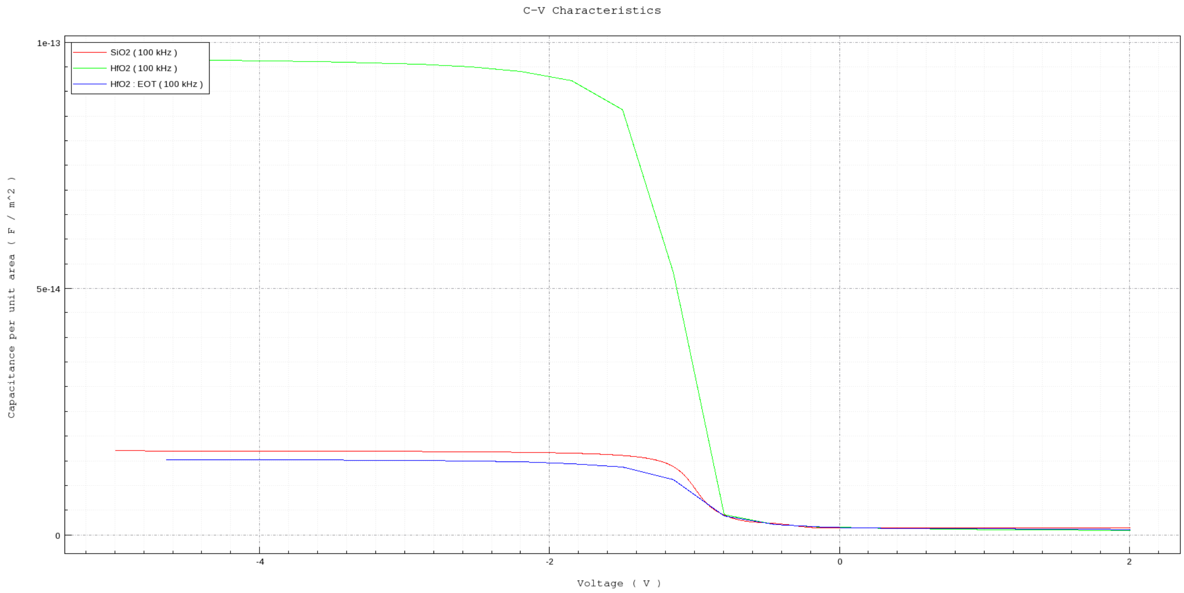
(a) Take gate-oxide (SiO_2) thickness t_{ox} = 2 nm and plot C-V characteristics.

(b) Now, replace the SiO_2 gate oxide with HfO_2 and plot C-V characteristics together with part (a). Write your observations and how this change of gate oxide affects the C-V & the threshold voltage.

(c) Use HfO_2 as gate-oxide with EOT of part (a) and plot the C-V together with part (a) & (b). Write your observations and how this change of gate oxide and EOT affects the C-V characteristics and the threshold voltage in all three cases.

RESULT AND CALCULATION

The plot of C-V characteristics is given below,



Replacing SiO_2 by HfO_2 leads to increase in capacitance in accumulation region as dielectric constant is higher for HfO_2. After applying equivalent oxide thickness the capacitance in accumulation region is almost equal for both oxides as in accumulation region of operation MOSCAP capacitance is equal to oxide capacitance. For all three cases the MOSCAP capacitance is equal to depletion capacitance in inversion region of operation due to high frequency of operation.