EE 735
Assignment –6

Total marks: 35

Q1. Consider a PN junction as shown in Figure 1; $N_A = 10^{17}$ cm^{-3} and $N_D = 10^{17}$ cm^{-3}

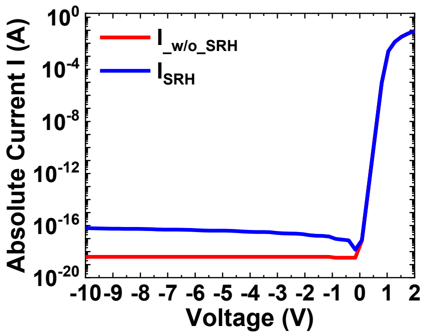
Plot the I-V in semi-log scale for the following cases with the voltage ranging from -10V to 2V: **[16]**

Note: For part (a) use only SRH and for part (b) use only band-to-band recombination models.

(a) SRH

(a.1) With and without SRH (Shockley-Read-Hall) recombination. Explain the difference in the I-V characteristics (if any). **[2 + 1 = 3]**

Answer:



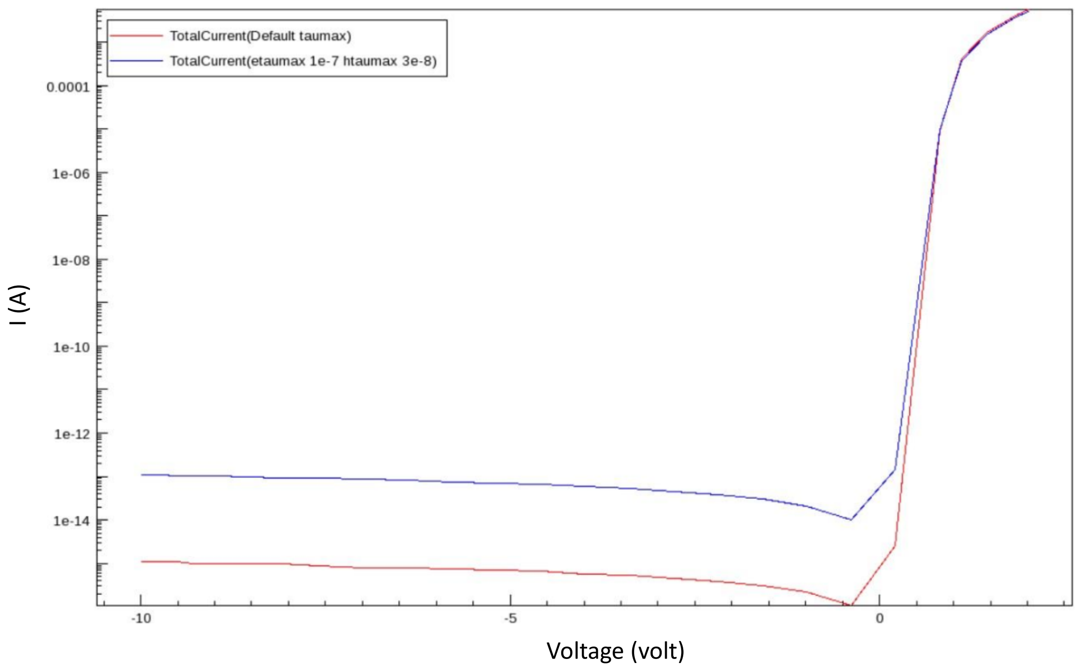
Without SRH, reverse saturation current actually saturates and constant till breakdown happens as there is no generation happening. In the forward bias direction also no recombination happens and no contribution from recombination SRH defects adds up to the forward current.

On the other hand, with SRH case, generation happens and increases with reverse bias (RB) as the RB increases the depletion width increases which actually serves as the active generation region and as a result, generation current increases in the RB. In, lower forward bias, recombination current dominates over diode diffusion current and this seen in the lower FB only.

(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). **[2 + 1 = 3]**

Answer:

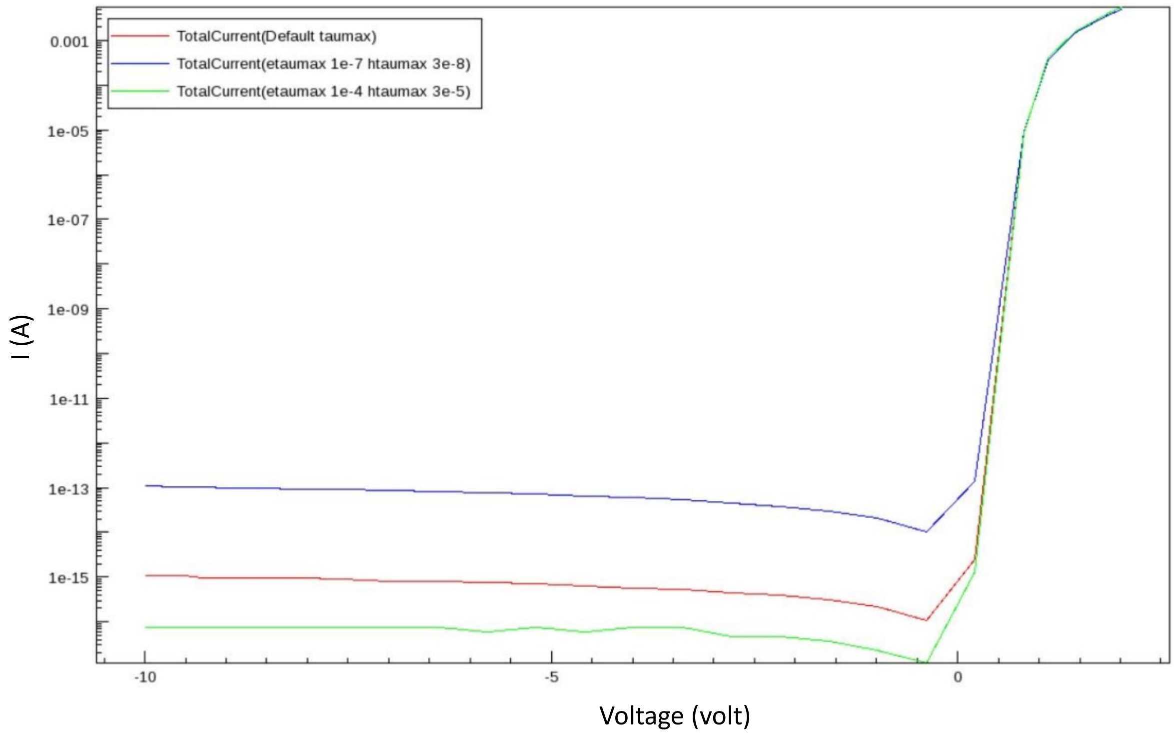
If you increase the minority carrier lifetime (taumax), which means the frequency of recombination-generation (R-G) decreases and hence the additional current due to R-G decreases which reduces the R-G current and thus overall current decreases. If you decrease the minority carrier lifetime, current will increase. For this question, 'taumax' of electron and hole have been decreased from the default value and hence, increased current is seen in the following plot. This effect is visible only in the RB and lower FB as seen in the plots.



(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). **[2 + 1 = 3]**

Answer:

Same explanation as above. In this case, $I_{R\text{-}G}$ will decrease as the taumax increased for both electron and holes.

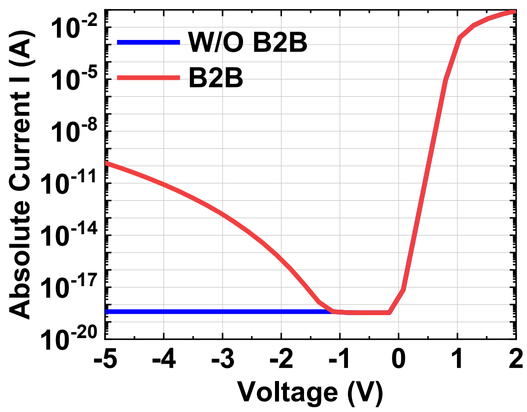


(b) <u>Band-to-band</u>

(b.1) With and without band-to-band recombination (E2 model). Explain the difference in the plots (if any). **[2 + 1 = 3]**

Answer:

With B2B recombination, you are essentially adding some extra current which is due to B2B recombination and hence With B2B, net current will higher than without case as seen in the plot.



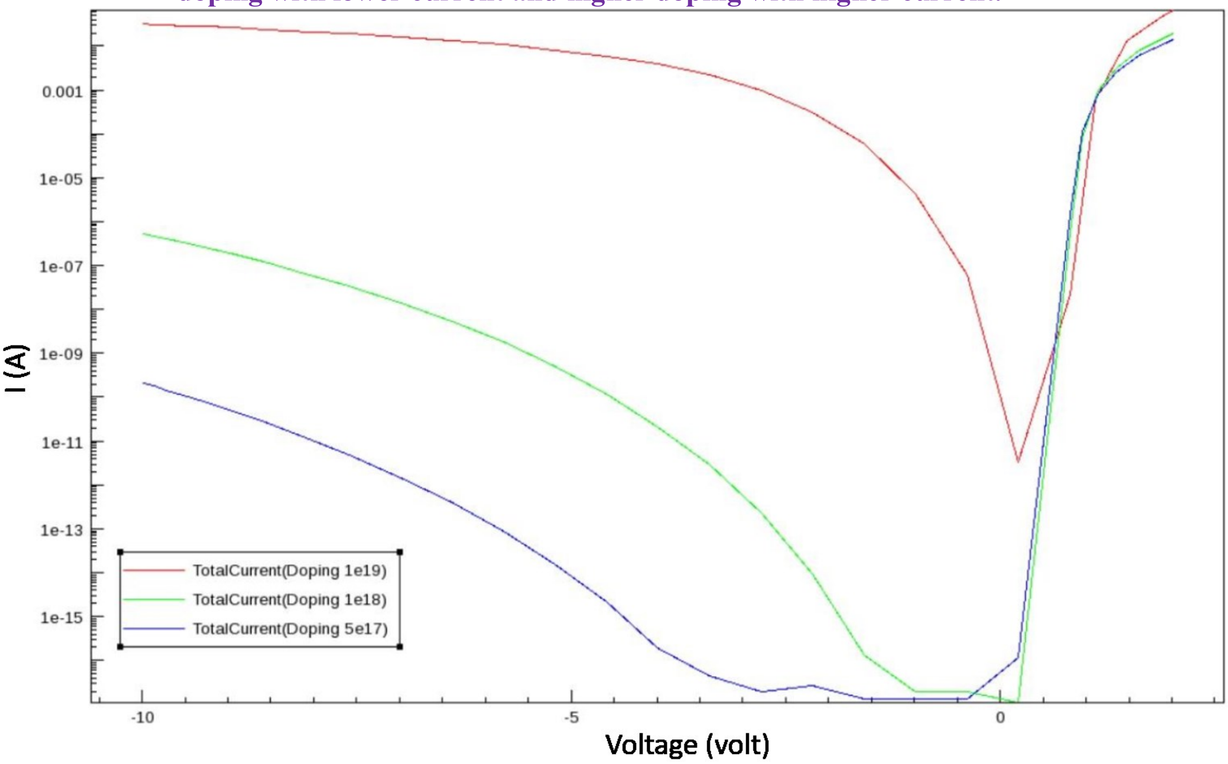
(b.2) For various doping levels of $N_A = N_D = 5x10^{17}$, 10^{18} and 10^{19} cm^{-3} with band-to-band recombination. Explain the trend. **[3 + 1 = 4]**

Answer:

There are two things:

(i) If you increase doping, depletion width decreases which is the tunneling barrier in RB and hence reverse current increases. There will be little increment in the forward current as well.

(ii) For any particular RB, electric field across the junction quadratically increases with doping which enhances the tunneling thereby reverse current too. You can observe this effect on the plot at point of RB voltage and see vertically, you can find, lower doping with lower current and higher doping with higher current.



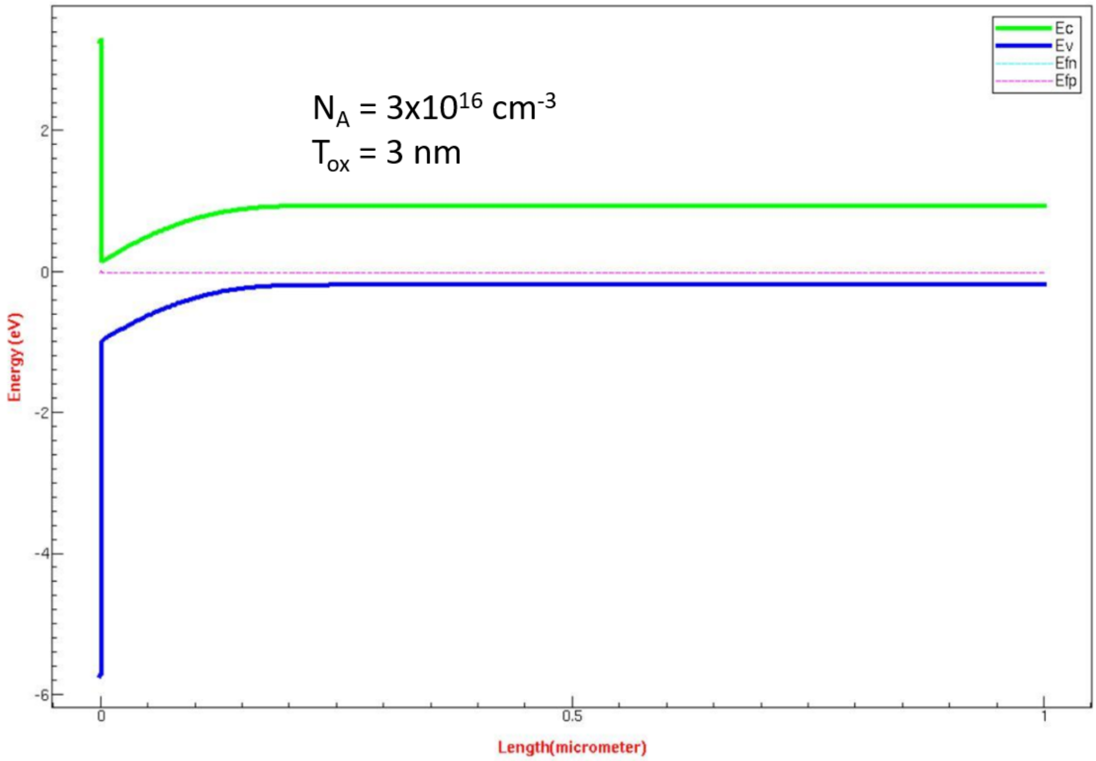
Q2. Simulate and plot the band diagram and charge profiles (electron and hole) of a MOS capacitor (n-MOS) biased at $V_g = V_T$ (inversion region) based on the data given in part (a). Use Al as gate metal. Figure 2 shows the schematic of a typical MOS device. Consider L = W = 1μm. [11]

a) Take gate-oxide (SiO_2) thickness t_{ox} = 3 nm and Si substrate doping $N_A = 3x10^{16}$ cm^{-3}. **[3]**

b) Now, change the SiO_2 thickness to 2 nm for the same substrate doping as in part-a. **[3]**

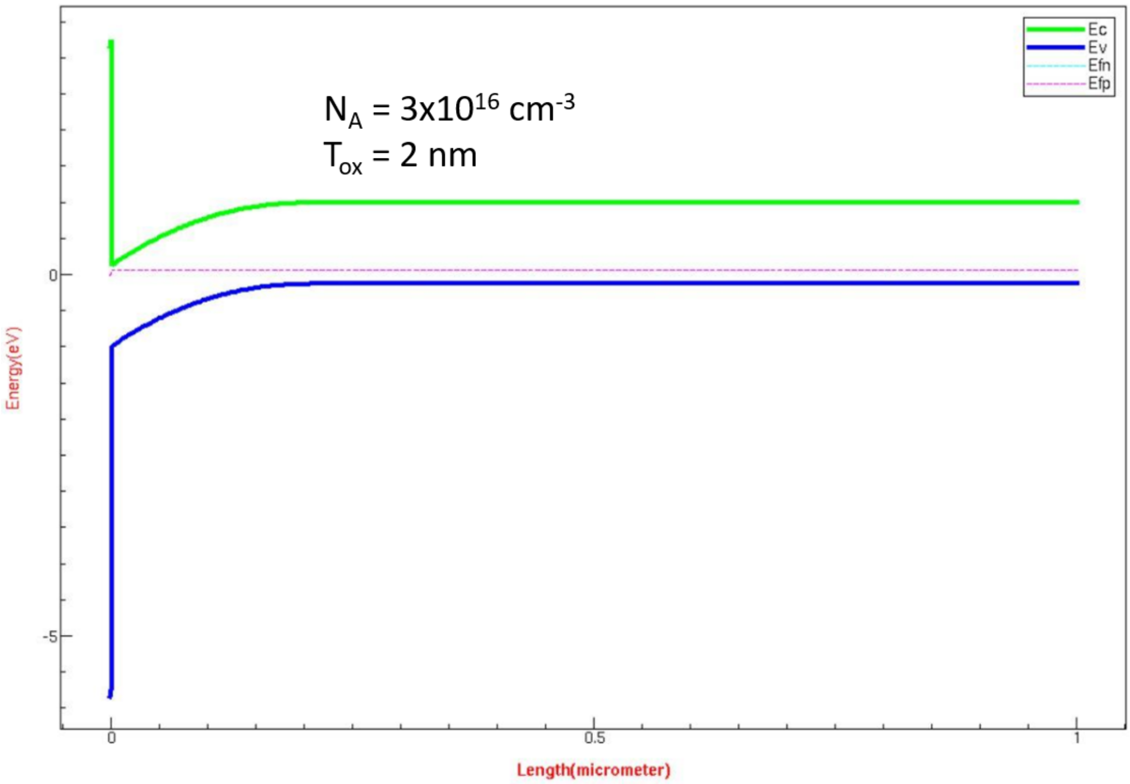
c) Consider t_{ox} = 3 nm and change the substrate doping to $N_A = 3x10^{17}$ cm^{-3}. **[3]**

Note: Please write your observations on how oxide thickness and substrate doping concentration affect the V_T. **[2]**

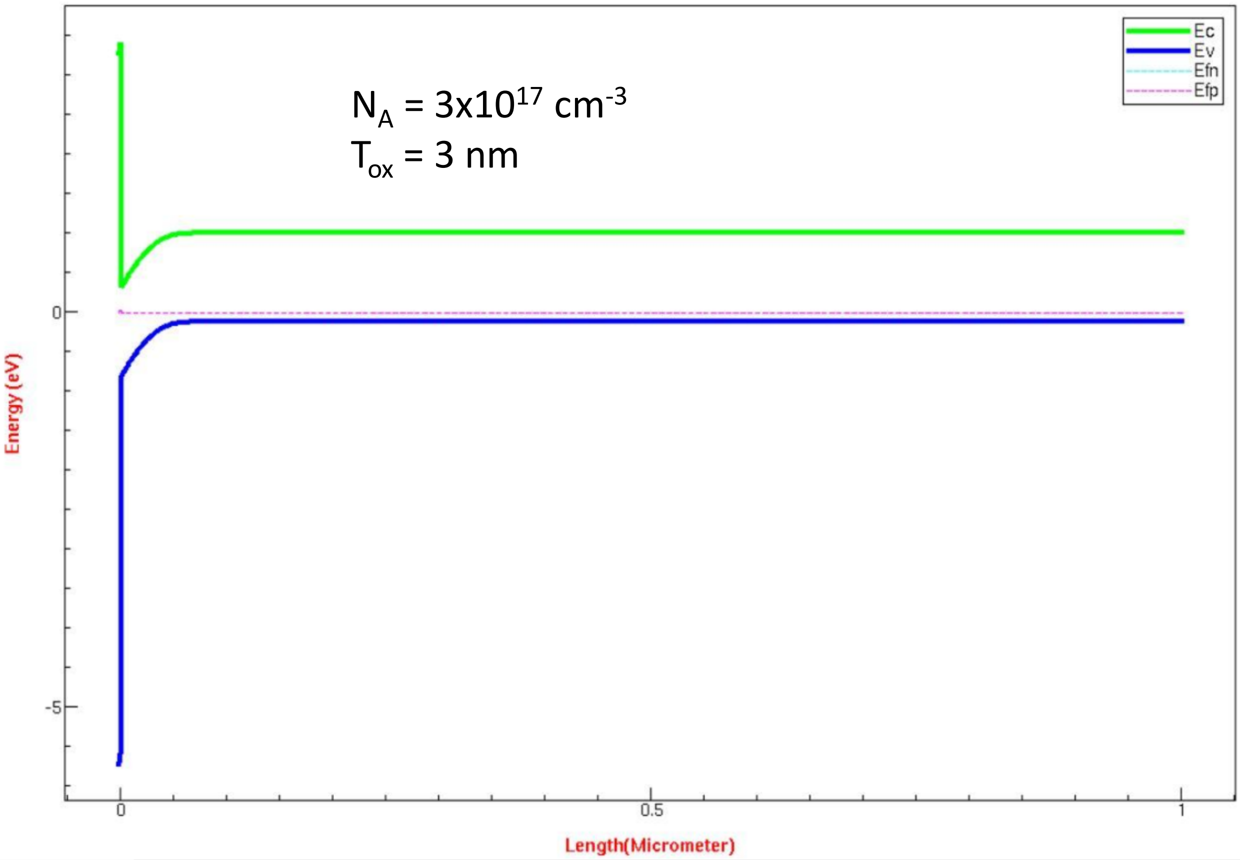


Observation:

Effect of oxide thickness: Upon decreasing oxide thickness from 3 nm to 2 nm in part (b), oxide capacitance will decrease which decreases the voltage drop across the oxide and thus surface potential will increase for a certain applied gate bias and this will quickly (with small gate bias) invert the channel quicker than the thicker oxide case. Hence, threshold voltage (V_T) will decrease with decreasing t_{ox}.



Effect of substrate doping [part (c)]: Increasing doping will increase the V_T as the requirement of inverted channel charge concentration has also increased with doping and you need to apply higher bias to get higher concentration of inverted channel charges.

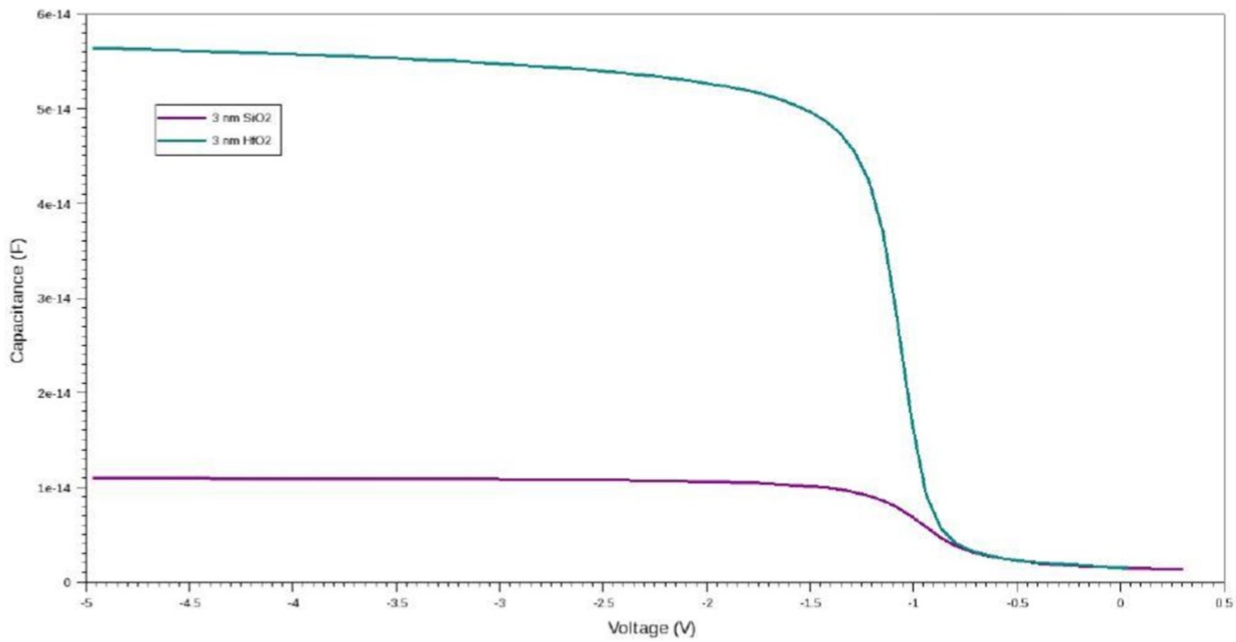


Q3. Simulate and plot the C-V (at 100 kHz) of a MOS capacitor (n-MOS) for a voltage range of -5V to 2V. Use substrate doping of $3x10^{17}$ cm^{-3} and Al as gate metal. Consider L = W = 1µm. [8]

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

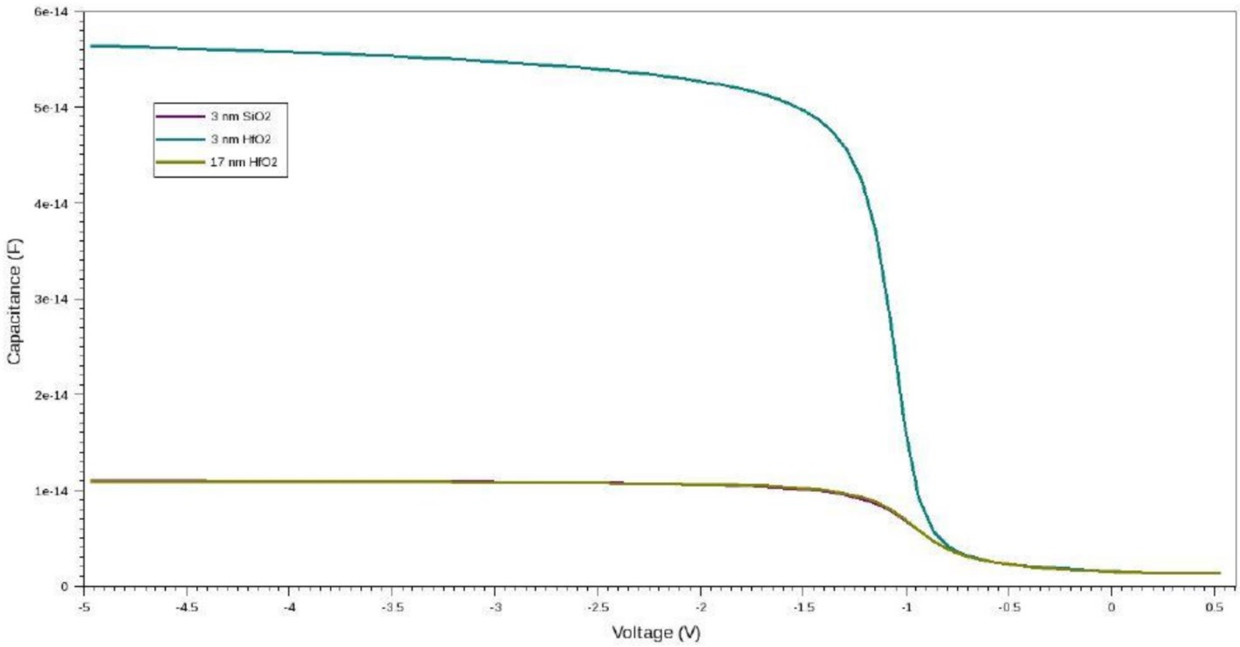
b) Now, replace the SiO_2 gate oxide with HfO_2 and plot C-V characteristics together with part (a). Write your observations and how this change of gate oxide affects the C-V & the threshold voltage. **[2 + 1 = 3]**

Observation: Dielectric constant of HfO_2 is 4 - 5 times than SiO_2 and hence the capacitance in HfO_2 case is higher than the SiO_2 case for 2 nm thickness of both as shown in the plot below. The effect is clearly seen in the accumulation region but not on the inversion region as the small signal frequency is high.



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. **[2 + 1 = 3]**

Observation: As we have chosen EOT of part (a), hence there will be no difference in capacitances between part (a) and part (c). However, the physical thickness of HfO_2 will be thicker than SiO_2 despite being similar capacitances shown by both part (a) and part (c) plotted the following figure.



Note: Apart from your explanation/observation, there is some portion of marks for proper plotting with proper axes names, clear legends and proper units included in simulation mark itself.