EE532: Device Simulation Lab

Experiment No. 2

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Experiment Name: Design of the MOSCAP using the Sentaurus Workbench Environment.

1 Design Parameters

Table 1: Design Parameters

Substrate	Silicon
Dopant	Boron
Doping	$5\times 10^{16} cm^{-3}$
Doping Type	Constant Profile Placement
Area of Substrate	100nm × 200nm
Oxide Thickness	20nm
Gate Metal	Aluminium
Metal thickness	40nm
Work function	5eV,4.7eV,4.5eV,4.3eV

2 Physics Models

Table 2: Physics Models

Parameters	Value/Type
Band gap and Bandgap narrowing	Effective intrinsic density (no band gap narrowing)
Mobility models	Mobility (Doping Dependence High Field Saturation)
Temperature (K)	300K
Traps	Fixed Charge

3 Device Structure

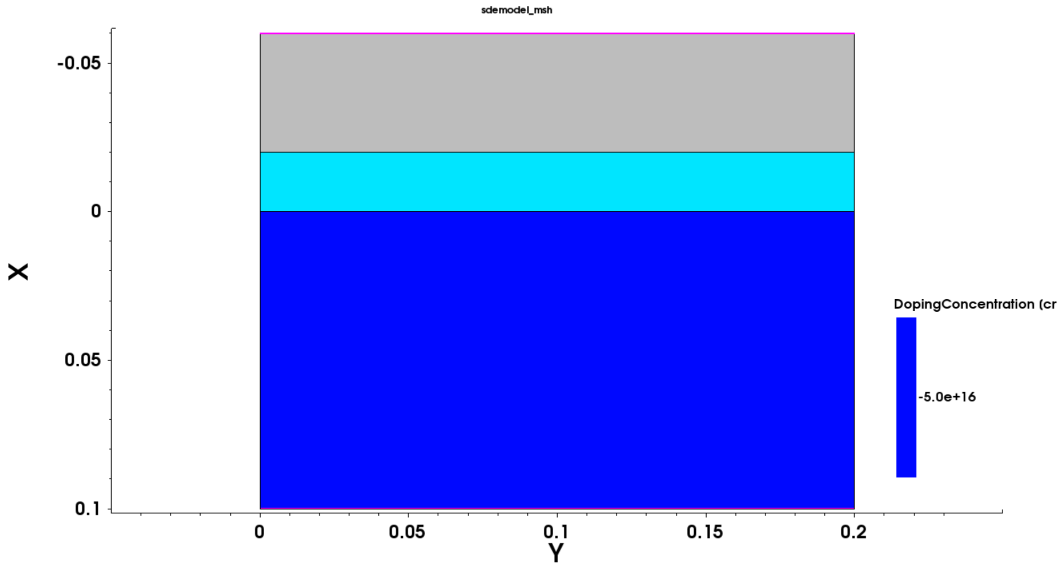

Figure 1: Schematic of the Moscap

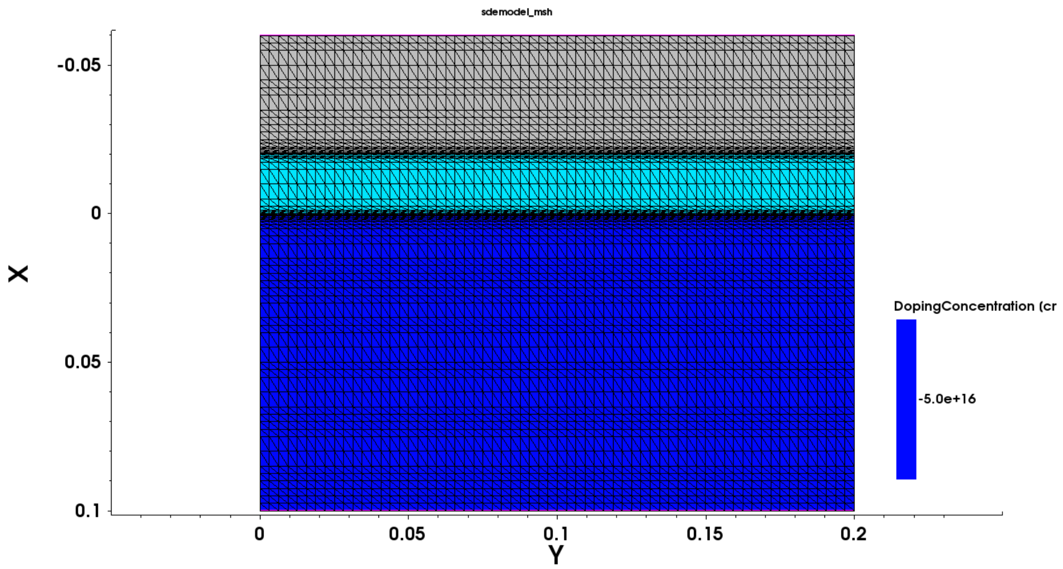

Figure 2: Schematic of the Moscap with meshing

4 Analysing the energy band diagrams

4.1 Flat Band condition

Here an ideal Moscap is created by taking the work function equal and providing a zero voltage across. The energy band diagram is then observed.

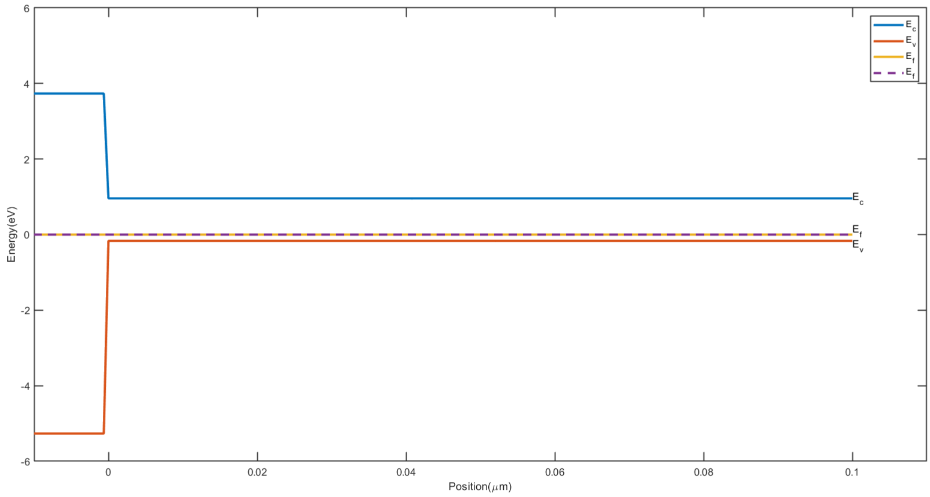

Figure 3: Energy band diagram at Flat band point

4.1.1 Calculating ϕ_f and Work function

$$\phi_f = V_t ln(\frac{N_a}{n_i}) \tag{1}$$

V_t is the thermal voltage = 26mV
n_i is the intrinsic carrier concentration=$1.5\times10^{10}/cm^{-3}$ N_a = Doping concentration = $5\times10^{16}cm^{-3}$
$\phi_f = 390.50mV$

$$\phi = \chi + \frac{E_g}{2} + \frac{kT}{q} ln(\frac{N_a}{n_i}) \tag{2}$$

χ = 4.05eV E_g = 1.12eV ϕ = 5V

4.2 Accumulation

The accumulation condition is observed when a negative voltage is applied in the moscap. As the majority holes are getting accumulated near the interface, the condition is called as accumulation.

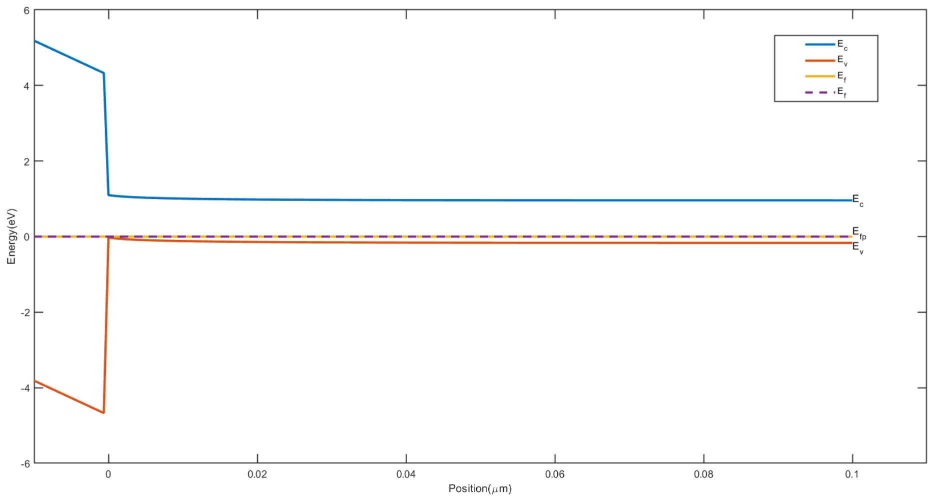

Figure 4: Energy band diagram in the accumulation region

4.3 Depletion

Now a small positive voltage is applied and the holes move away from the interface and there is a formation of negative immobile ions. This condition is called the depletion of majority carriers.

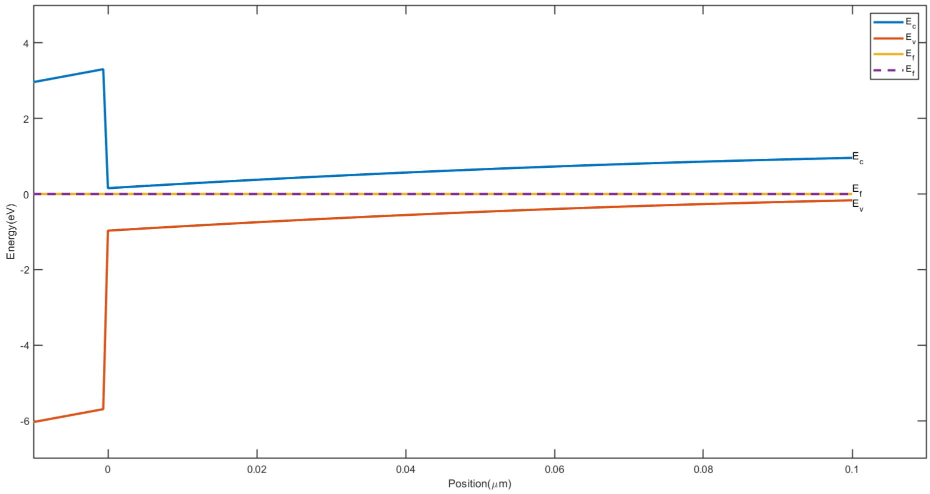

Figure 5: Band diagram in the depletion region

4.4 Inversion

As the applied positive voltage is increased there is a generation of minority electrons which then gets attracted towards the interface. Initially no electron gets attracted towards the interface as a potential is required for this process. As the electrons number at the interface increases and becomes equal to the majority concentration in the bulk, the inversion takes place.

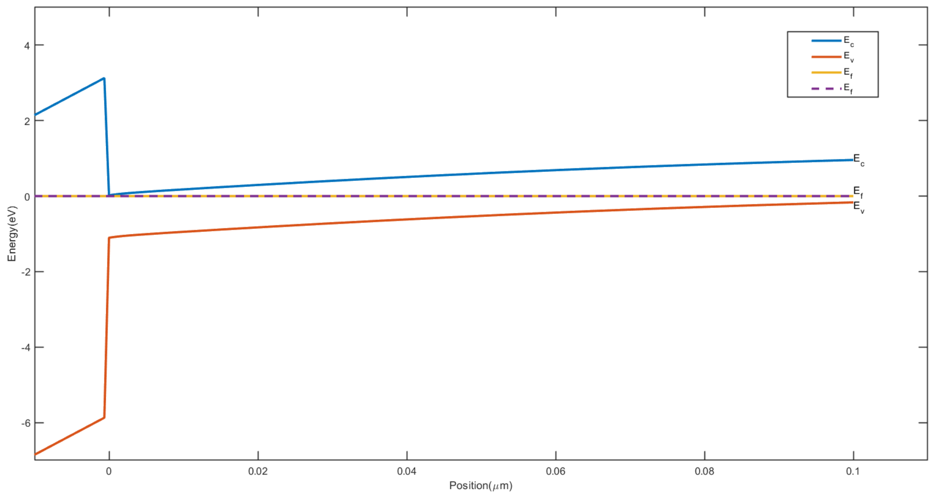

Figure 6: Band diagram in the inversion region

From the band diagram it can be observed that when the conduction band touches the Fermi level inversion takes place.

5 Plot C-V curve at three different frequencies in single plot

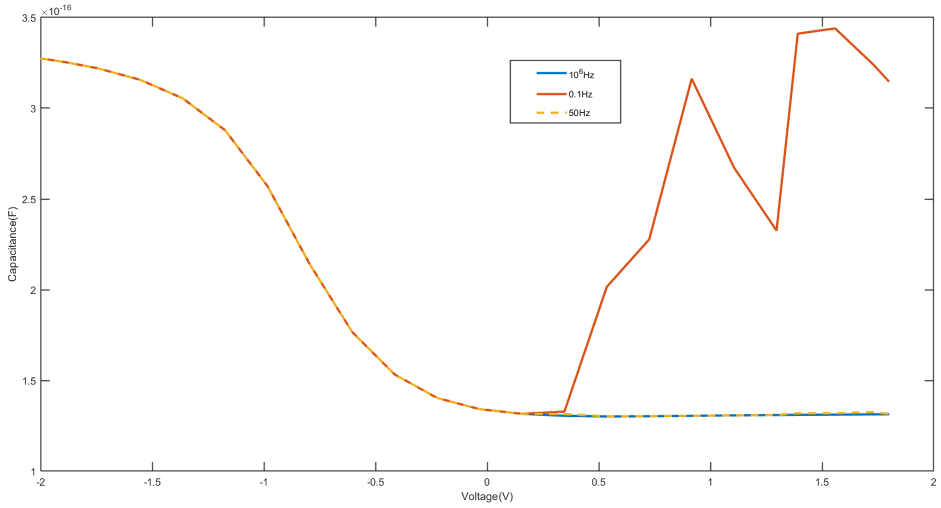

Figure 7: CV at different frequencies

When the voltage is negative, there are majority carriers on one side and electrons on the other side. The capacitance can be calculated very simply,

$$Q = C(V) \tag{3}$$

$$C = \frac{Q}{V} \tag{4}$$

where V is negative.

$$Q = -\epsilon E \tag{5}$$

$$C = \frac{\epsilon_{ox}}{t_{ox}} \tag{6}$$

When the frequency is low then initially on applying negative potential we can see the capacitance per unit area as

$$C = \frac{\epsilon_{ox}}{t_{ox}} \tag{7}$$

As the voltage is increased the depletion starts taking place and the capacitance starts reducing as the width of depletion region increases thereby reducing the capacitance of the region. The capacitance in the depletion region can be seen as the series combination of oxide capacitance and the depletion capacitance of the p type semiconductor.

$$\frac{1}{C} = \frac{1}{C_{ox}} + \frac{1}{C_{si}} \tag{8}$$

5.1 Calculating C_{ox}

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} \tag{9}$$

$\epsilon_{ox} = 8.85 \times 10^{-14} \times 3.9 F/cm$
t_{ox} = 20nm
$C_{ox} = 0.17265 \mu F cm^{-2}$

5.2 Calculating C$_{dep}$

$$W_t = [\frac{2K_s\epsilon_o}{qN_a}(2\phi_f)]^{1/2} = 0.14\mu m \tag{10}$$

$$C_{dep} = \frac{\epsilon}{W_t} = 0.74nFcm^{-2} \tag{11}$$

5.3 Calculating C$_{min}$

From (8),(10) and (11) we can say
$C_{min} = 0.753nFcm^2$

5.4 Calculating V$_{th}$

$$V_{th} = V_{fb} + 2\phi_f + \frac{K_s t_{ox}}{K_o}[\frac{2qN_a 2\phi_f}{K_s\epsilon_o}]^{1/2} \tag{12}$$

Putting the values $V_{th} = 1.47V$

Now as the voltage is further increased the generation of minority charge carriers takes place hence increasing the charge at the interface thereby resulting in the capacitance same as that observed in the accumulation. Now as the frequency is increased the plots remains same only variation comes after the inversion where due to the very high frequency the generation of the minority carriers is not possible.

6 Plot C-V curve at three different concentrations in single plot

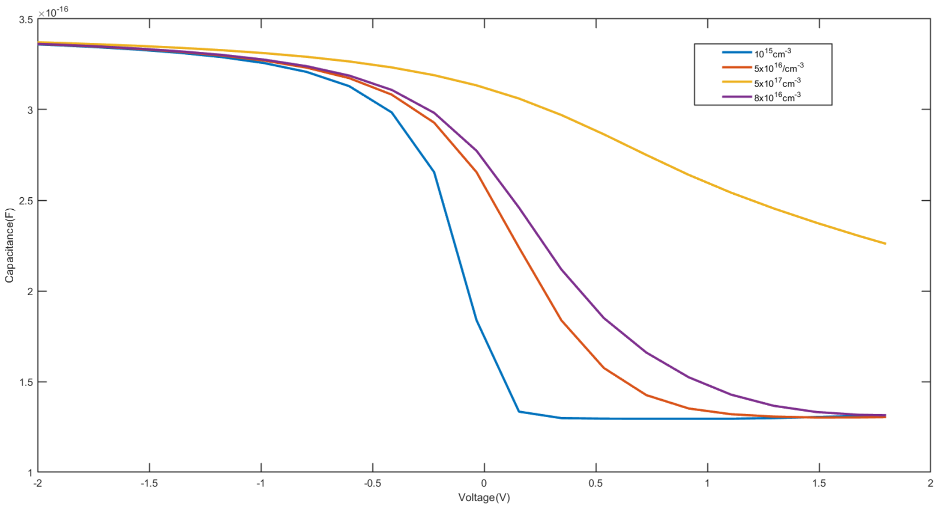

Figure 8: Effect of variation of Doping concentration on CV curve

When the concentration is changed the direct effect comes on to the V_{th}. When the concentration is increased the V_{th} is also increased hence there is a shift in the V_{th} to the right and when the concentration is reduced there is a left shift in the V_{th}. Now, $N_a = 1 \times 10^{15} cm^{-3}$ ϕ_f = 288.79mV, $N_a = 5 \times 10^{17} cm^{-3}$ ϕ_f = 450.373mV, $N_a = 8 \times 10^{16} cm^{-3}$ ϕ_f = 402.72mV.

$$V_{th} = V_{fb} + 2\phi_f + \frac{K_s t_{ox}}{K_o}[\frac{2qN_a 2\phi_f}{K_s\epsilon_o}]^{1/2} \tag{13}$$

For $N_a = 5 \times 10^{17} cm^{-3}$, $V_{th} = 3.14V$ For $N_a = 8 \times 10^{16} cm^{-3}$ $V_{th} = 1.65V$ For $N_a = 1 \times 10^{15} cm^{-3}$ $V_{th} = 0.66V$

7 Show the impact of different metal work function in single plot

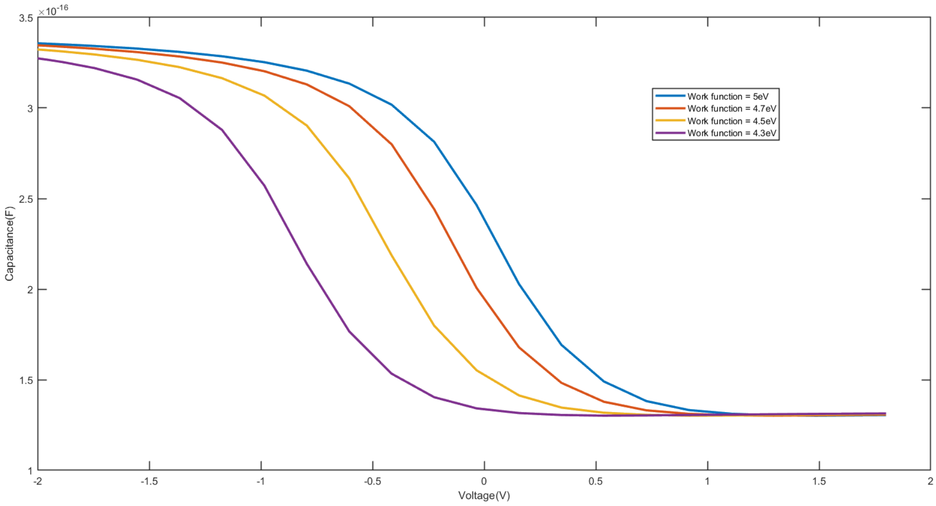

Figure 9: Effect of work function change on the CV curve

7.1 Calculating V$_{th}$

$$V'_{th} = V_{fb} + V_{th} \tag{14}$$

V_{fb} = 0V for metal work fn = 5eV, V_{fb} = -0.3V for metal work fn = 4.7eV, V_{fb} = -0.5V for metal work fn = 4.5eV, V_{fb} = -0.7V for metal work fn = 4.3eV Metal work function affects the V_{th} values as the negative work function will help reduce the V_{th} and the positive value will increase the threshold voltage value.

$V'_{th} = 1.17V$ for V_{fb} = -0.3V
$V'_{th} = 0.97V$ for V_{fb} = -0.5V
$V'_{th} = 0.77V$ for V_{fb} = -0.7V

8 Plot C-F curve of moscap in different region.

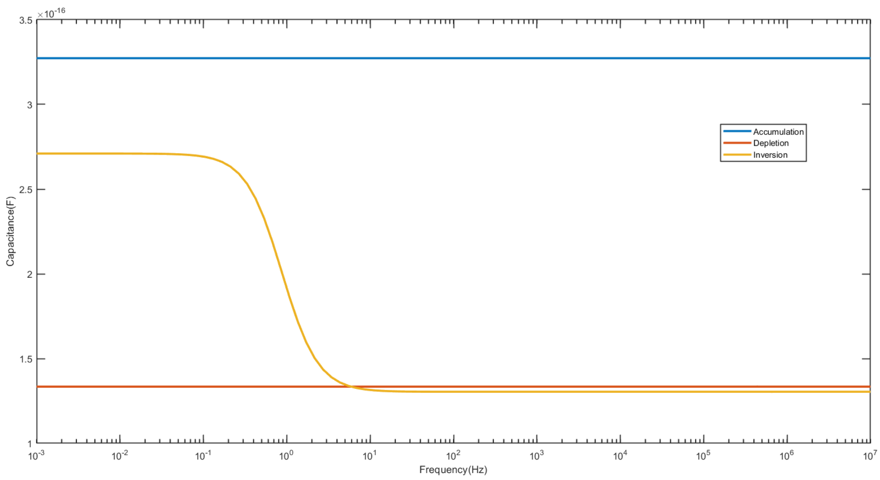

Figure 10: Capacitance frequency curve at different regions in Moscap

With the change in frequency there is a change in the capacitance values in the inversion region only as discussed above. The other region's capacitance stays almost constant.

9 Show the effect of fixed charge on the CV curve for at least three values of fixed charge.

The fixed charges can also affect the value of V_{th}. If the fixed charge is positive then it will reduce the V_{th} and if it is negative then V_{th} will increased.

9.1 Calculating V$_{th}$

$$V_{th} = V_{fb} + 2\phi_f - \frac{Q_d}{C_{ox}} \tag{15}$$

Here $V_{fb} = \frac{-Q_f}{C_{ox}} = -0.093V$ $Q_f = 1 \times 10^{11} Ccm^{-3}$ $V_{th}' = 1.47 - 0.093 = 1.377V$
For $Q_f = 0Ccm^{-2}$. $V_{th} = V_{th}'$
$Q_f = -1 \times 10^{11} Ccm^{-2}$ $V_{th}' = 1.563V$

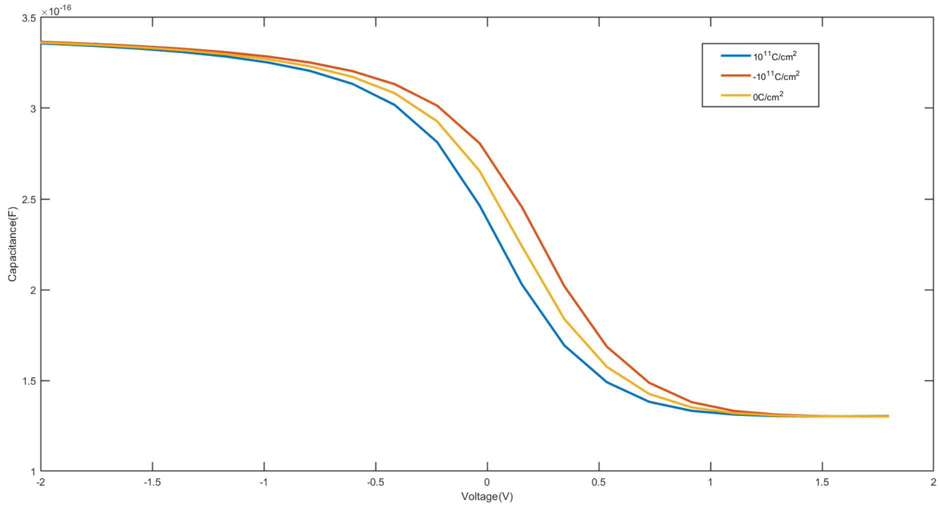

Figure 11: Capacitance frequency curve at different regions in Moscap

10 Conclusion

In this experiment moscap was created using the script command and then its various regions of operations were analysed, the energy band diagrams were analysed and then the CV characteristics under different situations such as different work functions, different dopings and different frequency. CF curves in all regions is also observed and at last effect of fixed charge was observed.