NAME:

1. Design an MIS Capacitor on a p-type <100> silicon substrate to have a VT of .5V if the fixed oxide charge is $5 \times 10^{10} q/cm^2$, $NA = 1 \times 10^{16} cm^{-3}$, and the permittivity of the oxide layer is $3.9 \times 8.85 \times 10^{-14}$F/cm. The gate material is heavily doped n-poly-silicon. (Room temperature conditions apply.)

NAME:

$T := 300$ $k := 1.38\cdot 10^{-23}$ $q := 1.6\cdot 10^{-19}$

$U_T := \frac{k\cdot T}{q}$ $V_T := 0.5$

$\chi := 4.05$ $\phi_n := 0$ $E_g := 1.12$ $n_i := 9.65\cdot 10^{9}$

$\phi_m := \chi + \phi_n$ $N_A := 10^{16}$

$U_T = 0.026$

$\Psi_B := U_T\cdot \ln\left(\frac{N_A}{n_i}\right)$ $\Psi_B = 0.358$ $\varepsilon_{SiO2} := 3.9\cdot 8.85\cdot 10^{-14}$

$\phi_{ms} := \frac{-E_g}{2} - \Psi_B$ $\phi_{ms} = -0.918$ $\varepsilon_{Si} := 11.8\cdot 8.85\cdot 10^{-14}$

$$Q_i := 5\cdot 10^{10}\cdot q \qquad Q_D := -2\cdot\left(\varepsilon_{Si}\cdot q\cdot N_A\cdot\phi_F\right)^{\frac{1}{2}}$$

$$V_T = \phi_{ms} - \frac{Q_i}{C_{ox}} - \frac{Q_D}{C_{ox}} + 2\cdot\phi_F$$

$$\frac{Q_i + Q_D}{C_{ox}} = -V_T + \phi_{ms} + 2\cdot\phi_F$$

$$\frac{1}{C_{ox}} = \frac{-V_T + \phi_{ms} + 2\cdot\phi_F}{Q_i + Q_D}$$

$$\frac{1}{\frac{\varepsilon_{Si02}}{d}} = \frac{-V_T + \phi_{ms} + 2\cdot\phi_F}{Q_i + Q_D}$$

$$d := \varepsilon_{SiO2}\cdot\left(\frac{-V_T + \phi_{ms} + 2\cdot\phi_F}{Q_i + Q_D}\right)$$

$d = 5.915\times 10^{-6}$ This is in cm!

NAME:

Design an MIS Capacitor on a n-type <100> silicon substrate to have a VT of -1V if the fixed oxide charge is $5x10^{10}q/cm^2$, tox=d=600Å, and the permittivity of the oxide layer is $3.9x8.85x10^{-14}$F/cm. The gate material is heavily doped n-poly-silicon. (Room temperature conditions apply.)

$V_T := -1$ $\qquad N_D := 10^{15}$

Given

$$V_T = \frac{-E_g}{2} + U_T \cdot \ln\left(\frac{N_D}{n_i}\right) - \frac{Q_i}{C_{ox}} - \frac{2\cdot\left(\varepsilon_{Si}\cdot q\cdot N_D\cdot\phi_F\right)^{\frac{1}{2}}}{C_{ox}} - 2\cdot\left(U_T\cdot\ln\left(\frac{N_D}{n_i}\right)\right)$$

$N_D := \text{Find}(N_D)$ $\qquad N_D = 6.97\times 10^{13}$

2. Design an MIS Capacitor on a p-type <100> silicon substrate to have a VT of .6V if the fixed oxide charge is $3x10^{10}q/cm^2$, and the permittivity of the oxide layer is $3.9x8.85x10^{-14}F/cm$. The gate material is Aluminum. Verify your design with Sentaurus using the MIS sample file located at: http://www.engr.sjsu.edu/dparent/ee225a/mis_simple.gzp

$T := 300 \qquad k := 1.38 \cdot 10^{-23} \qquad q := 1.6 \cdot 10^{-19}$

$U_T := \frac{k \cdot T}{q} \qquad V_T := 0.6$

$\chi := 4.28 \qquad \phi_n := 0 \qquad E_g := 1.12 \qquad n_i := 9.65 \cdot 10^{9}$

$\phi_m := \chi + \phi_n \qquad N_A := 10^{16}$

$U_T = 0.026$

$\Psi_B := U_T \cdot \ln\left(\frac{N_A}{n_i}\right) \qquad \Psi_B = 0.358 \qquad \varepsilon_{SiO2} := 3.9 \cdot 8.85 \cdot 10^{-14}$

$\phi_{ms} := \frac{-E_g}{2} - \Psi_B \qquad \phi_{ms} = -0.918 \qquad \varepsilon_{Si} := 11.8 \cdot 8.85 \cdot 10^{-14}$

$$Q_i := 3 \cdot 10^{10} \cdot q \qquad Q_D := -2 \cdot \left(\varepsilon_{Si} \cdot q \cdot N_A \cdot \phi_F\right)^{\frac{1}{2}}$$

$$V_T = \phi_{ms} - \frac{Q_i}{C_{ox}} - \frac{Q_D}{C_{ox}} + 2 \cdot \phi_F$$

$$\frac{Q_i + Q_D}{C_{ox}} = -V_T + \phi_{ms} + 2 \cdot \phi_F$$

$$\frac{1}{C_{ox}} = \frac{-V_T + \phi_{ms} + 2 \cdot \phi_F}{Q_i + Q_D}$$

$$\frac{1}{\frac{\varepsilon_{Si02}}{d}} = \frac{-V_T + \phi_{ms} + 2 \cdot \phi_F}{Q_i + Q_D}$$

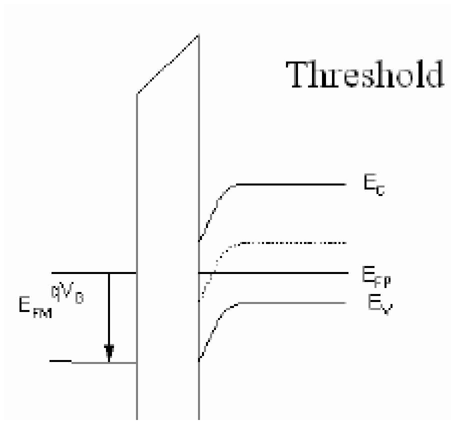
$$d := \varepsilon_{SiO2} \cdot \left(\frac{-V_T + \phi_{ms} + 2 \cdot \phi_F}{Q_i + Q_D}\right)$$

$d = 6.268 \times 10^{-6}$ This is in cm!

TOX	NA	NG		QSS		VT	NA_CV	N	Qi
0.06268	1e16	10	--	3e10	--	0.94	9.28e+15	1.63	-1.06e+11
		20	--	3e10	--	0.70	8.91e+15	1.62	-3.23e+10
		30	--	3e10	--	0.70	8.91e+15	1.62	-3.23e+10
		40	--	3e10	--	0.64	9.60e+15	1.64	1.72e+09
		50	--	3e10	--	0.64	9.60e+15	1.64	1.72e+09
		60	--	3e10	--	0.64	9.60e+15	1.64	1.72e+09
		70	--	3e10	--	0.64	9.60e+15	1.64	1.72e+09
		80	--	3e10	--	0.61	9.97e+15	1.65	1.69e+10
		90	--	3e10	--	0.61	9.97e+15	1.65	1.69e+10
0.061	1e16	10	--	3e10	--	0.91	9.36e+15	1.61	-1.07e+11
		20	--	3e10	--	0.68	8.99e+15	1.60	-3.24e+10
		30	--	3e10	--	0.68	8.99e+15	1.60	-3.24e+10
		40	--	3e10	--	0.62	9.68e+15	1.62	1.64e+09
		50	--	3e10	--	0.62	9.68e+15	1.62	1.64e+09
		60	--	3e10	--	0.62	9.68e+15	1.62	1.64e+09
		70	--	3e10	--	0.62	9.68e+15	1.62	1.64e+09
		80	--	3e10	--	0.60	1.01e+16	1.63	1.69e+10
		90	--	3e10	--	0.60	1.01e+16	1.63	1.69e+10

We can see the best grid is between 70 and 80. The final TOX is 610 Angstroms. The difference between the CV simulation and hand calculations is that the depletion width maximum is simplified to values in the hand calculations.

3. Draw the EGB of an MIS Capacitor on a p-type <100> silicon substrate where VG=VT. (Room temperature conditions apply.)



The intrinsic level at the surface is the same distance below the Fermi level that it is above the Fermi level in the bulk.

4. As you remember the number of grid points affects the time a TCAD simulation has to run, and the accuracy of the simulation. In the case of the MIS diode from question #1, up to what point would you need a fine grid to accurately simulate the MIS diode?

   The grids have to vary from a tight grid inside the deletion region up to the depletion width maximum.

5. The figure below shows the measured CV data of a MIS capacitor on p-type <100> silicon substrate with an aluminum gate (ϕ_{ms}=-.6ev-UTxln(NA/ni)) (The Insulator is Si02.) Extract d, (tox) NA, VT, and fixed oxide charge. (Room temperature conditions apply.) Hint, you do not have to scale the measured data by the area.

NAME:

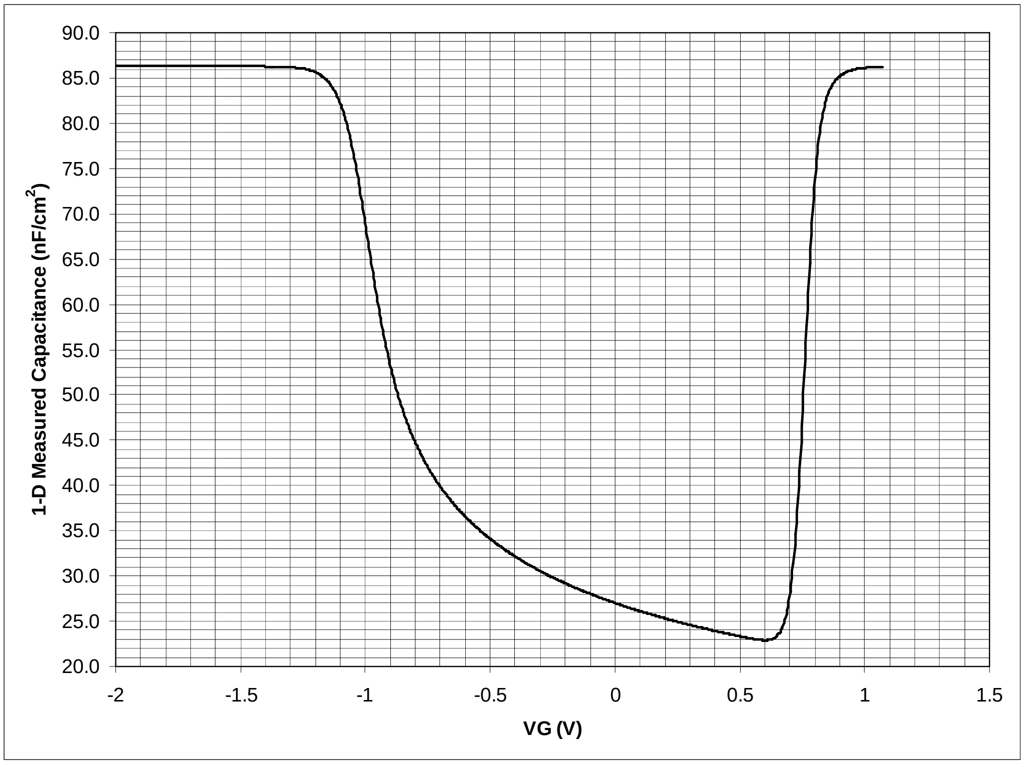


Figure 1: Measured 1-D CV plot of MIS capacitor.

VFB from the reverse look up of the chart is -1V

From the Graph

$$C_{g\_max} := 86 \cdot 10^{-9} \frac{F}{cm^2}$$

$$C_{g\_min} := 23 \cdot 10^{-9} \frac{F}{cm^2}$$

$$C_{g\_min} = \frac{C_{si\_min} \cdot C_{g\_max}}{C_{si\_min} + C_{g\_max}}$$

$$C_{si\_min} := \frac{C_{g\_max} \cdot C_{g\_min}}{C_{g\_max} - C_{g\_min}}$$

$$C_{si\_min} = 3.14 \times 10^{-8} \frac{F}{cm^2}$$

$$N_b := 10^{30.388+1.683\cdot\log(C_{si\_min})-0.03177\cdot\log(C_{si\_min})^2}$$

$$N_b = 9.369\times 10^{15}$$

$$L_D := \sqrt{\frac{\varepsilon_{si}\cdot U_T}{q\cdot N_b}} \quad L_D = 4.283\times 10^{-6}$$

$$C_{Debye} := \frac{\varepsilon_{si}\cdot\sqrt{2}}{L_D} \quad C_{Debye} = 3.506\times 10^{-7}$$

$$C_{g\_max} := \frac{C_{g\_max}}{\frac{F}{cm^2}}$$

$$C_{FB} := \frac{C_{g\_max}\cdot C_{Debye}}{C_{g\_max}+C_{Debye}} \quad C_{FB} = 6.906\times 10^{-8}$$

VFB from the reverse look up of the chart is -1V

$$ni := 9.65 \cdot 10^{10}$$

+ $$V_{FB} := -1$$

$$Q_D := -2 \cdot \left(\varepsilon_{si} \cdot q \cdot N_b \cdot U_T \cdot \ln\left(\frac{N_b}{ni}\right)\right)^{\frac{1}{2}} \qquad Q_D = -4.352 \times 10^{-8}$$

$$V_T := V_{FB} - \frac{Q_D}{C_{ox}} + 2 \cdot 0.0259 \cdot \ln\left(\frac{N_b}{ni}\right) \qquad V_T = 0.101$$

$$V_{FB} = \phi_{ms} - \frac{Q_i}{C_{g\_max}} \qquad \phi_{ms} := -0.6 - U_T \cdot \ln\left(\frac{N_b}{ni}\right)$$

$$\phi_{ms} = -0.897$$

$$Q_i := \left(-V_{FB} + \phi_{ms}\right) \cdot C_{g\_max} \qquad V_{FB} = -1$$

$$Q_i = 8.822 \times 10^{-9}$$

TOX=400 Angstroms.