金氧半電容元件 作業二 112,10,3 學號：R11941039 姓名：蔡明軒

Si: election affinity = 4.15 eV, E_g = 1.12 eV, ε_{Si} = 11.9 ε_0, $\varepsilon_0 = 8.85\times10^{-14}$ F/cm, 常溫下 $n_i = 1.5\times10^{10}\ cm^{-3}$, kT/q = 0.0259 V, 假設 $E_i \simeq \frac{1}{2}(E_c+E_v)$ 成立, 金屬 Al 之 $q\phi_m$ = 4.1 eV, SiO_2 $\varepsilon_{SiO_2} = 3.9\varepsilon_0$, 存在 Qeff 及 Dit, 其中 Dit 在 E_i 以上呈 acceptor-type, 以下呈 donor-type, 公式 $V_G = \left[\phi_{ms} - \frac{Q_{eff}}{C_{ox}} - \frac{Q_{it}(\psi_s=0)}{C_{ox}}\right] - \frac{[Q_{it}(\psi_s) - Q_{it}(\psi_s=0)]}{C_{ox}} - \frac{Q_s(\psi_s)}{C_{ox}} + \psi_s$,

1. 對於 MOS(p)元件, d_{ox} = 500Å, $N_A = 1\times10^{14}\ cm^{-3}$, $D_{it} = 2.5\times10^{11}\ cm^{-2}\cdot eV^{-1}$(假設均分布於 Eg 內), $Q_{eff}/q = 2\times10^{11}\ cm^{-2}$, 其 V_{FB} = -1.4338 (V), 於 flat-band 時 $C_{HF}/C_{ox} = C_{FB}/C_{ox}$ = 0.2698, C_{LF}/C_{ox} = 0.4869。同理 MOS(n)元件, $N_D = 1\times10^{14}\ cm^{-3}$, Dit 及 Qeff 同上, 其 V_{FB} = -0.7134 (V) 於 flat-band 時 $C_{HF} = C_{FB}/C_{ox}$ = 0.2698, C_{LF}/C_{ox} = 0.4896。

2. MOS(p)元件, d_{ox}、N_A、Dit, Qeff 值同題 1, 當偏壓至 $\psi_s = |\phi_B|$ 時, V_G = -1.0358 (V) 其 $Q_{it}(\psi_s)$ = 0, C_{HF}/C_{ox} = 0.0809, C_{LF}/C_{ox} = 0.4085。(假設 $Q_s \simeq Q_D$ 成立, $C_s(\psi_s)$ 可引用至高頻)

3. 在繪製 $C_{HF}-V_G$ 特性曲線時, MOS(p)元件於 $\psi_s \le |\phi_B|$ 前, $\frac{1}{C_{HF}} = \frac{1}{C_{ox}} + \frac{1}{C_s(\psi_s)}$ 可引用, 於 $\psi_s > |\phi_B|$ 時, $C_s(\psi_s) \simeq C_D(\psi_s) = \varepsilon_s/W_D(\psi_s)$ 趨近之, 亦即 $\frac{1}{C_{HF}} \simeq \frac{1}{C_{ox}} + \frac{1}{C_D(\psi_s)}$。
對於 MOS(p)元件, d_{ox} = 500Å, $N_A = 1\times10^{14}\ cm^{-3}$, $Q_{eff}/q = 2\times10^{11}\ cm^{-2}$, 請繪出 $D_{it} = 0$, $D_{it} = 2.5\times10^{11}\ cm^{-2}\cdot eV^{-1}$, 及 $D_{it} = 1\times10^{12}\ cm^{-2}\cdot eV^{-1}$ 三種條件下於 V_G = -5 V 至 +2 V 範圍內之高頻 $C_{HF}-V_G$ 或低頻 $C_{LF}-V_G$ 曲線(共三組六條), Dit 屬性同題 1。(六小題計)

4. MOS(p)元件, $Q_{eff}/q = 2\times10^{11}\ cm^{-2}$, $D_{it} = 2.5\times10^{11}\ cm^{-2}\cdot eV^{-1}$(屬性同題1), $N_A = 1\times10^{14}\ cm^{-3}$, 請繪出 $d_{ox(a)}$ = 200Å, $d_{ox(b)}$ = 500Å, $d_{ox(c)}$ = 1000Å 三種條件下於 V_G = -5 V 至 +2 V 範圍內之高頻 $C_{HF}-V_G$ 或低頻 $C_{LF}-V_G$ 曲線(共三組六條)(六小題計)

(a) 將三組高頻之 C_{HF}/C_{ox} 繪在一起呈現三條曲線(二小題計), 求 $V_{FB(a)}$ = -1.0763 (V), $V_{FB(b)}$ = -1.4338 (V), $V_{FB(c)}$ = -2.0295 (V)

(b) 將三組低頻之 C_{LF}/C_{ox} 繪在一起呈現三條曲線(二小題計), 求 $C_{LF}/C_{ox}|_{V_{FB(a)}}$ = 0.2751, $C_{LF}/C_{ox}|_{V_{FB(b)}}$ = 0.4869, $C_{LF}/C_{ox}|_{V_{FB(c)}}$ = 0.6549.

(請於 112,10,10 前將 Pdf 檔上傳 NTU Cool, 逾期不收, 演算過程請一併附上, _____ 欄請填寫答案!)

1.

$Q_{eff}/q = 2\times10^{11}\ cm^{-2}$

$d_{ox} = 500\ \text{Å}$

$N_A = 1\times10^{14}\ cm^{-3}$

$D_{it} = 2.5\times10^{11}\ cm^{-2}eV^{-1}$

$$V_{FB} = \phi_{ms} - \frac{Q_{eff}}{C_{ox}} - \frac{Q_{it}(\psi_s=0)}{C_{ox}}$$

$$C_{ox} = \frac{3.9\times8.85\times10^{-14}}{50\times10^{-9}} = 6.903\times10^{-8}$$

$$\phi_{ms} = 4.1 - \left[4.15 + \frac{1.12}{2} + 0.0259\ln\frac{n_i}{N_A}\right] = -0.838$$

$$E_i - E_F = 0.0259\ln\frac{N_A}{n_i} = 0.2280$$

$$D_{it} = \frac{-1}{q}\frac{dQ_{it}}{dE} \Rightarrow \frac{Q_{it}}{q} = -\int D_{it}\,dE$$

$$\frac{Q_{it}(\psi_s=0)}{q} = (E_i - E_F)\,D_{it}$$

$$= 5.7012\times10^{10}$$

$$V_{FB} = -0.838 - 0.4636 - 0.1321$$

$$\Rightarrow V_{FB} = \boxed{-1.4338}\ (V)$$

$$\frac{C_{FB}}{C_{ox}} = \frac{C_{FBS}}{(C_{ox}+C_{FBS})}$$

$$C_{FBS} = \frac{\epsilon_s}{\lambda_p}$$

$$\lambda_p = \sqrt{\frac{kT\epsilon_s}{q^2 N_A}} = 4.1289\times10^{-5}\ cm$$

$$\Rightarrow C_{FBS} = \frac{11.9\epsilon_0}{4.1289\times10^{-5}} = 2.55\times10^{-8}\ F/cm$$

$$\frac{C_{FB}}{C_{ox}} = \frac{2.55\times10^{-8}}{(6.903\times10^{-8}+2.55\times10^{-8})}$$

$$\Rightarrow \frac{C_{FB}}{C_{ox}} = \boxed{0.2698}$$

Flat Band $\Rightarrow \psi_s = 0$

$$C_s(\psi_s=0) = C_{FBS}$$

$$C_{LF} = \left[\frac{1}{C_{ox}} + \frac{1}{C_s(0)+C_{it}}\right]^{-1}$$

$$C_{it} = q\times D_{it} = 4\times10^{-8}\ F/cm$$

$$C_{LF} = 3.3611\times10^{-8}\ F/cm$$

$$\boxed{\frac{C_{LF}}{C_{ox}} = 0.4869}$$

1.

$N_d = 1\times10^{14}\ cm^{-3}$

$V_{FB} = \phi_{ms} - \frac{Q_{eff}}{C_{ox}} - \frac{Q_{it}(\psi_s=0)}{C_{ox}}$

$C_{ox} = \frac{3.9\times 8.85\times10^{-14}}{50\times10^{-9}} = 6.903\times10^{-8}$

$\phi_{ms} = 4.1 - \left[4.15 + \frac{1.12}{2} - 0.0259\ln\frac{n_i}{N_A}\right] = -0.382$

$E_F - E_i = 0.0259\ln\frac{N_d}{n_i} = 0.2280$

$D_{it} = \frac{-1}{q}\frac{dQ_{it}}{dE} \Rightarrow \frac{Q_{it}}{q} = -\int D_{it}\,dE$

$\frac{Q_{it}(\psi_s=0)}{q} = (E_F - E_i)\,D_{it}$

$= -5.7612\times10^{10}$

$V_{FB} = -0.382 - 0.4638 - (-0.1321) \Rightarrow$

$\Rightarrow \boxed{V_{FB} = -0.7134\ (V)}$

$N_A = N_D$

$\Rightarrow \lambda_n = \lambda_p$

$\Rightarrow C_{FBN} = C_{FBP}$

$\Rightarrow \frac{C_{FB}}{C_{ox}} = \boxed{0.2698}$

$\begin{cases} D_{it}(n) = D_{it}(p) \\ C_{FBN} = C_{FBP} \end{cases}$

$\Rightarrow \begin{cases} C_{itn} = C_{itp} \\ C_{sn}(\psi_s=0) = C_{sp}(\psi_s=0) \end{cases}$

$\frac{C_{LF}}{C_{ox}} = \boxed{0.4869}$

2.

$d_{ox} = 5 \times 10^{-6}$ cm

$N_A = 1 \times 10^{14}$ cm^{-3}

$D_{it} = 2.5 \times 10^{11}$ cm$^{-3} \cdot$ eV^{-1}

$Q_{eff}/q = 2 \times 10^{11}$ cm^{-2}

$\psi_S = |\phi_B|$

$$V_G = V_{FB} + V_{ox} + \psi_S$$

$$\Rightarrow V_G = \phi_{MS} - \frac{Q_{eff}}{C_{ox}} - \frac{Q_S(\psi_S)}{C_{ox}} - \frac{Q_{it}(\psi_S)}{C_{ox}} + \psi_S$$

$$\phi_B = E_F - E_i = -kT \ln \frac{N_A}{n_i} = -0.228$$

$$Q_{it}/q = -D_{it} \times q \times (\phi_B + \psi_S) = \boxed{0}$$

$$\phi_S = \phi_B + \psi_S = 0.456$$

$$u_S = \frac{q\phi_S}{kT} = 17.6098$$

$$u_B = \frac{q\phi_B}{kT} = 8.8049$$

$$F_S = -7.2379 \times 10^{14}$$

$$Q_S = \varepsilon_S F_S = -7.6226 \times 10^{-8}$$

$$V_{FB} = -1.1695$$

$$V_g = V_{FB} - \frac{Q_S}{C_{ox}} - \left[\frac{Q_{it} - Q_{it}(0)}{C_{ox}}\right] + \psi_S$$

$$= \boxed{-1.0358 \text{ (V)}}$$

$$C_{HF} = \left[\frac{1}{C_{ox}} + \frac{1}{C_{HFS}(\psi_S)}\right]^{-1}$$

$$\psi_S = |\phi_B| \Rightarrow C_{HFS}(\psi_S) = C_D$$

$$C_D = \varepsilon_S / W_D$$

$$W_D = \sqrt{\frac{2\psi_S \varepsilon_S}{qN_A}} = 3 \times 10^{-5}$$

$$C_D = 6.0783 \times 10^{-9}$$

$$C_{HF} = 5.5864 \times 10^{-9}$$

$$\frac{C_{HF}}{C_{ox}} = \boxed{0.0809}$$

$$C_{LF} = \left[\frac{1}{C_{ox}} + \frac{1}{C_S(\psi_S) + C_{it}}\right]^{-1}$$

$$C_{it} = q \times D_{it} = 4 \times 10^{-8}$$

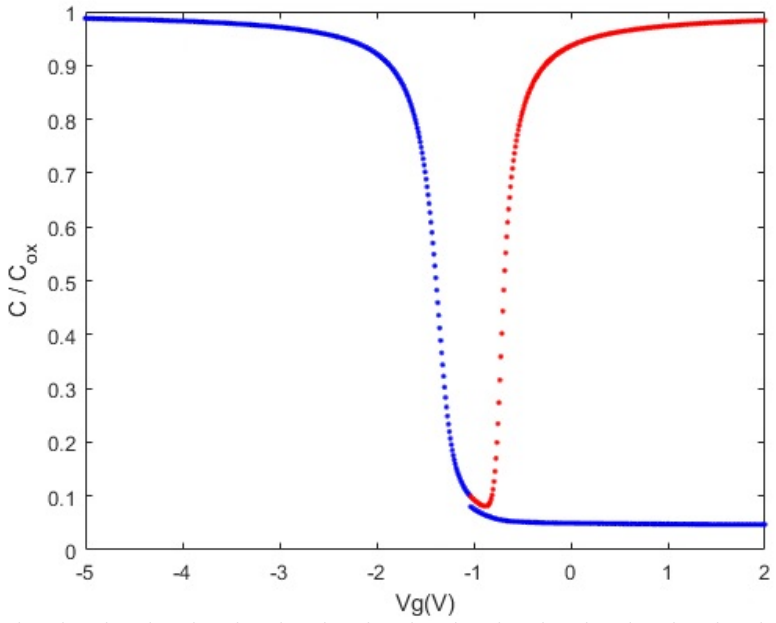
$$C_S = 7.6773 \times 10^{-9}$$

$$C_{LF} = 2.82 \times 10^{-8}$$

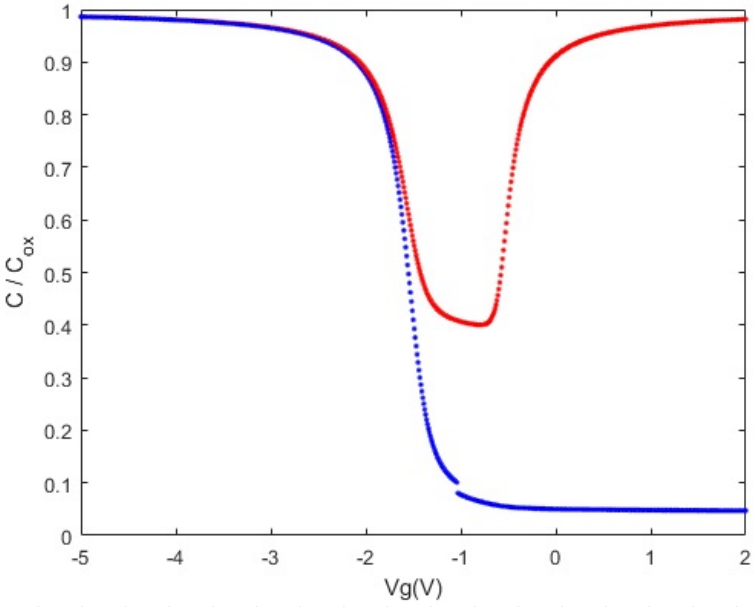
$$\frac{C_{LF}}{C_{ox}} = \boxed{0.4085}$$

3.

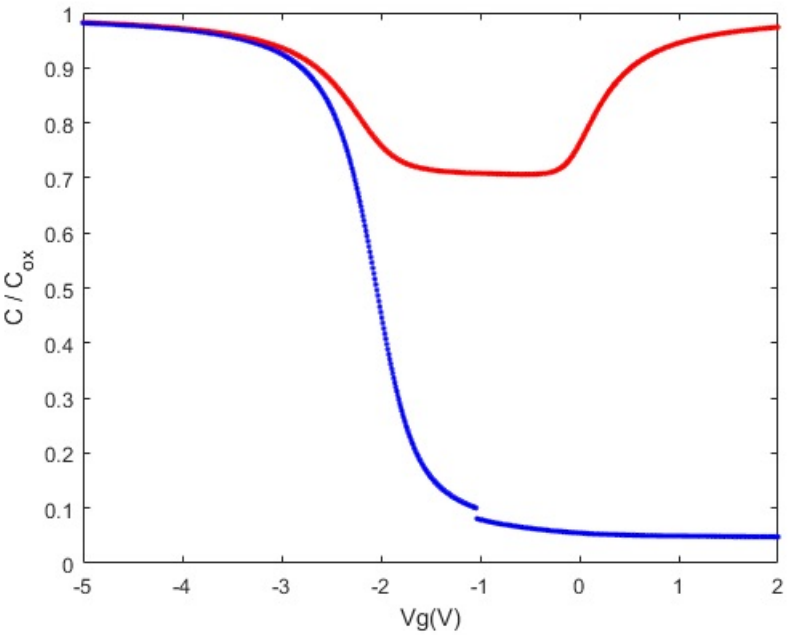
$D_{it}=0$



$D_{it}=2.5\times10^{11}\ (cm^{-2})$

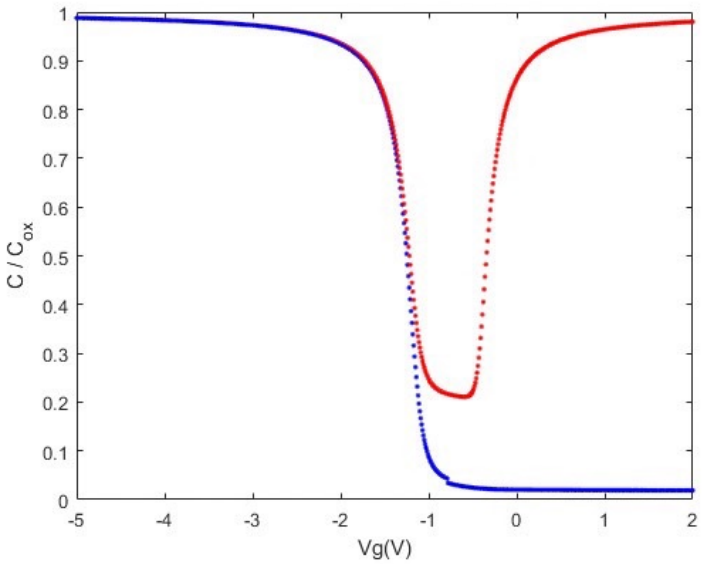


$D_{it}=1\times10^{12}\ (cm^{-2})$

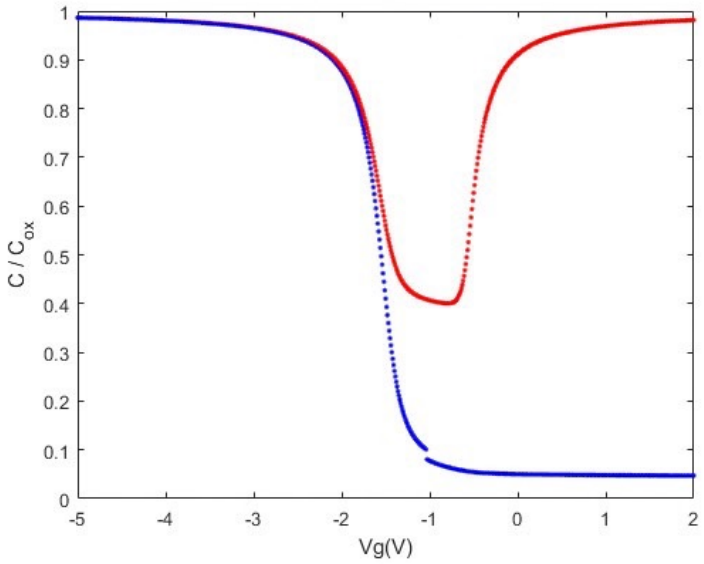


4.

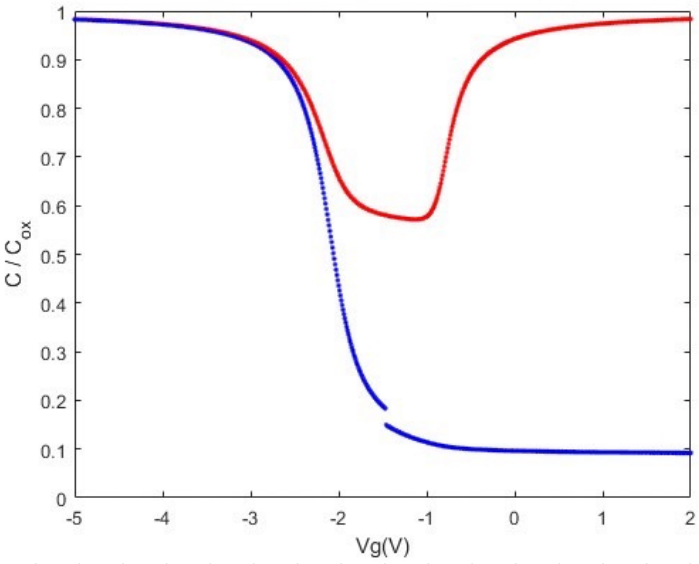
$d_{ox} = 100$ Å



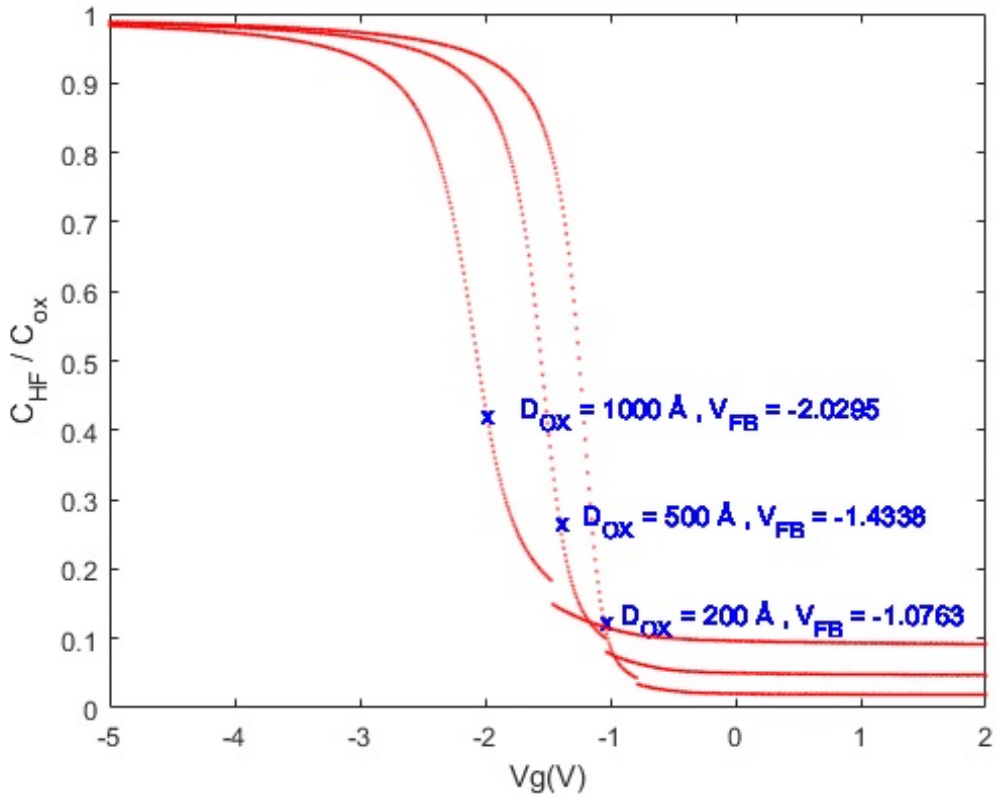
$d_{ox} = 500$ Å



$d_{ox} = 1000$ Å



4. (HF)

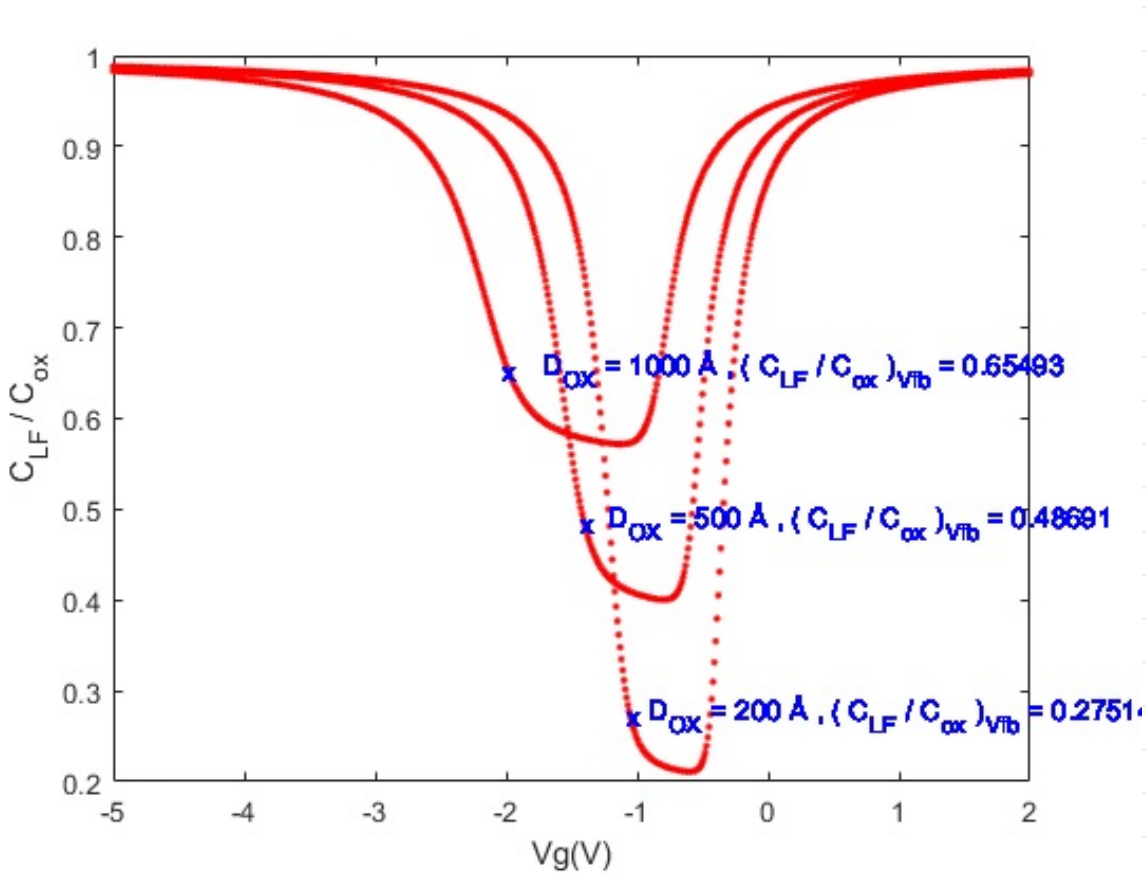


d_{ox} 200 Å $\Rightarrow$ $V_{FB}(a) = -1.0763$ (V)

d_{ox} = 500 Å $\Rightarrow$ $V_{FB}(b) = -1.4338$ (V)

d_{ox} = 1000 Å $\Rightarrow$ $V_{FB}(c) = -2.0295$ (V)

4. (LF)



$d_{ox} = 200$ Å $\Rightarrow \left(\frac{C_{LF}}{C_{ox}}\right)_{V_{FB(a)}} = 0.2751$

$d_{ox} = 500$ Å $\Rightarrow \left(\frac{C_{LF}}{C_{ox}}\right)_{V_{FB(b)}} = 0.4869$

$d_{ox} = 1000$ Å $\Rightarrow \left(\frac{C_{LF}}{C_{ox}}\right)_{V_{FB(c)}} = 0.6549$