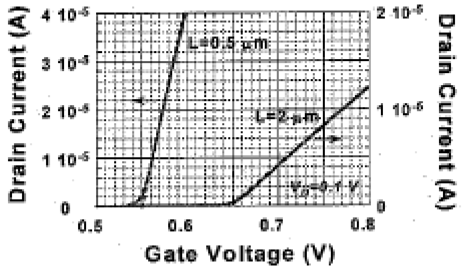
[Chapter 4 solution]

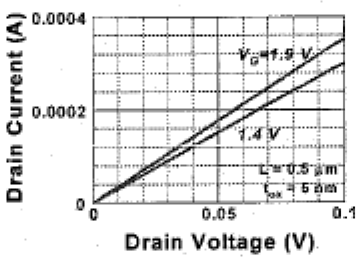
4.15 Fitting straight lines to the $I_D - V_G$ plots gives the intercepts V_{GSi}: 0.55 V and 0.65 V.
Using $V_T = V_{Gi} - V_D/2$, gives V_T (0.5 μm) = 0.5 V and V_T (2 μm) = 0.6 V. Fitting straight lines to the $I_D - V_D$ plots gives:

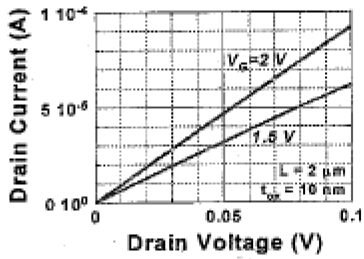
L (μm)	$V_G - V_T$ (V)	R_m (Ohms)	L (μm)	$V_G - V_T$ (V)	R_m (Ohms)
0.5	1.4	283	2	1.4	1087
0.5	0.9	333	2	0.9	1613

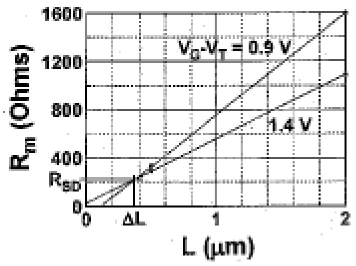
From the $R_m - L$ plot, ΔL = 0.35 μm and R_{SD} = 220 ohms.

$$\mu_{eff} = \frac{g_d L_{eff}}{W C_{ox}(V_G - V_T)} = \frac{9.2\mathrm{x}10^{-4}\,\mathrm{x}1.65\mathrm{x}10^{-4}}{10^{-3}\,\mathrm{x}3.45\mathrm{x}10^{-7}\,\mathrm{x}1.4} = 315\ cm^2/V-s$$





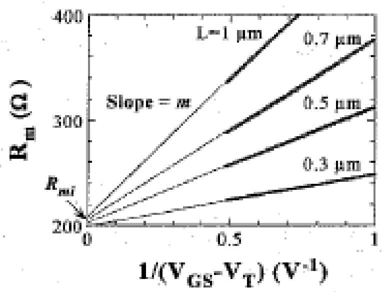


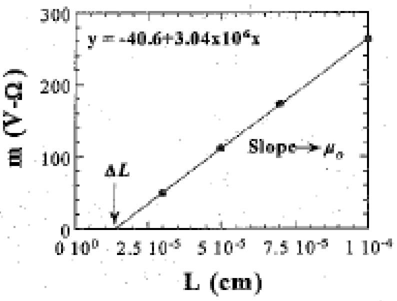


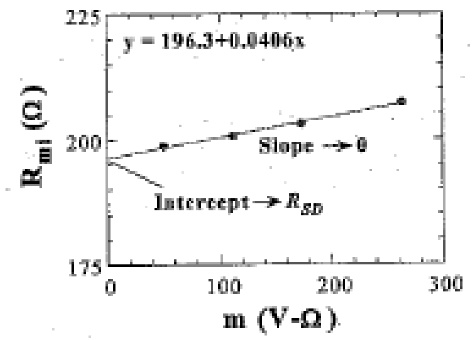
***V_T* (0.5 μm) = 0.5 V; *V_T* (2 μm) = 0.6 V;**
Δ*L* = 0.35 μm; *R_{SD}* = 220 ohms;
***μ_{eff}* = 315 cm²/V-s**

4.17 $R_m = V_{DS}/I_D$ versus $1/(V_{GS}-V_T)$ curves are measured on MOSFETs with various gate lengths. Curve fitting gives: y = 198.7+50x; y = 200.6+112x; y = 203+173x; y = 207.3+263x.
From the $R_m - 1/(V_{GS}-V_T)$ curves, determine R_{mi} and m. Then plot m versus L and R_{mi} versus m.

$$R_m = \frac{L-\Delta L}{W_{eff}\mu_o C_{ox}(V_{GS}-V_T)} + \frac{\theta(L-\Delta L)}{W_{eff}\mu_o C_{ox}} + R_{SD}\,;\quad \frac{dR_m}{d[1/(V_{GS}-V_T)]} = m = \frac{L-\Delta L}{W_{eff}\mu_o C_{ox}}\,;\quad \frac{dm}{dL} = \frac{1}{W_{eff}\mu_o C_{ox}}\,;\quad \frac{dR_{mi}}{dm} = \theta$$

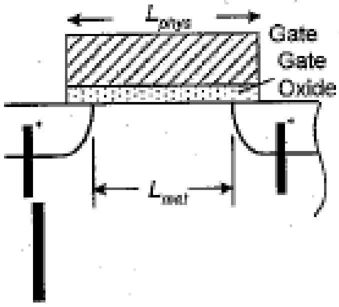






ΔL = 0.13 μm, μ_o = 475 cm^2/V-s, R_{SD} = 196 Ω, θ = 0.04 V^{-1}

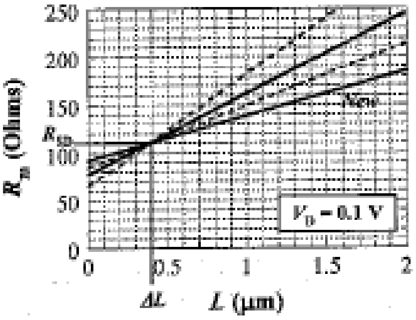
4.18 Yes, if the gate-induced electron channel extends into the source and drain at high gate voltages.



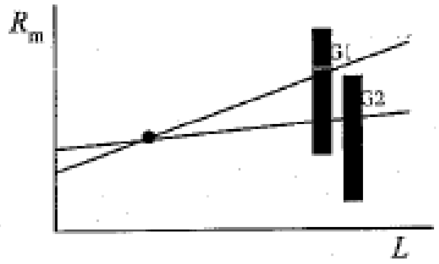
4.19 R_{SD} = 110 Ω, Δ_L = 0.4 μm.

$$R_m = \frac{V_D}{I_D} = \frac{t_{ox}(L-\Delta L)}{W\mu_{eff}K_{ox}\varepsilon_o(V_G - V_T)}\,;\; Slope = \frac{dR_{mi}}{L} = \frac{t_{ox}}{W\mu_{eff}K_{ox}\varepsilon_o(V_G - V_T)}$$

$$t_{ox} \Downarrow \Rightarrow V_T \Downarrow \Rightarrow (V_G - V_T) \Uparrow \therefore slope \Downarrow$$



4.19



4.20

[Chapter 5 solution]

Exercise 5.2는 solution이 있음.

5.1 (a) $\delta C = \dfrac{n_T(0)}{2N_D} C_0 \left(\exp\left(-\dfrac{t_2}{\tau_e}\right) - \exp\left(-\dfrac{t_1}{\tau_e}\right) \right) = \Delta C_o \left(\exp\left(-\dfrac{t_2}{\tau_e}\right) - \exp\left(-\dfrac{t_1}{\tau_e}\right) \right)$ is a maximum when $d\delta C/dT=0$.

$$\frac{d\delta C}{dT} = \Delta C_o \left[e^{-t_2/\tau_e} \left(-\frac{t_2}{\tau_e} \frac{d(1/\tau_e)}{dT} \right) - e^{-t_1/\tau_e} \left(-\frac{t_1}{\tau_e} \frac{d(1/\tau_e)}{dT} \right) \right] = \Delta C_o \frac{d(1/\tau_e)}{dT} \left[e^{-t_2/\tau_e} \left(-\frac{t_2}{\tau_e} \right) - e^{-t_1/\tau_e} \left(-\frac{t_1}{\tau_e} \right) \right] = 0$$

This can be equal to zero only if the []=0, i.e., $t_1 \exp(-t_1/\tau_e) = t_2 \exp(-t_2/\tau_e)$ or $\boxed{\tau_{e,\max} = \dfrac{t_2 - t_1}{\ln(t_2/t_1)} = \dfrac{t_1(r-1)}{\ln(r)}}$.

(b) $\delta C = \Delta C_o \left(\exp(-t_2/\tau_e) - \exp(-t_1/\tau_e) \right) = \Delta C_o \left(\exp(-(t_2/t_1) t_1/\tau_e) - \exp(-t_1/\tau_e) \right)$;

using $x=\exp(-t_1/\tau_e)$ and $r=t_2/t_1$ gives $\delta C = \Delta C_o (x^r - x)$. The peak in the δC-x curve occurs when $\delta C/dx=0$.

This gives $x_{\max} = r^{-1/(r-1)}$.

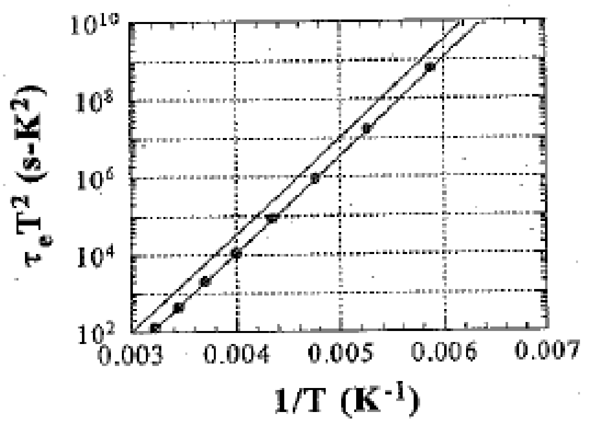
Substituting $x_{\max}$ into the original "δC" equation give

$$\delta C_{\max} = \Delta C_o (x_{\max}^r - x_{\max}) = \Delta C_o x_{\max} (x_{\max}^{r-1} - 1) = \Delta C_o r^{-1/(r-1)} (r^{-(r-1)/(r-1)} - 1) = \Delta C_o r^{-1/(r-1)} (1/r - 1)$$

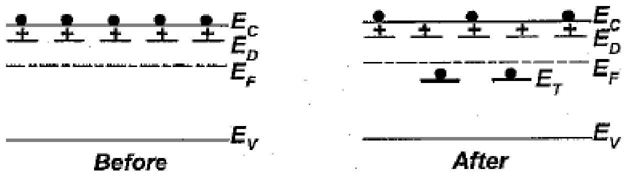
$$\boxed{\delta C_{\max} = \Delta C_o r^{-1/(r-1)} \left(\frac{1}{r} - 1 \right) = \Delta C_o \frac{1-r}{r r^{1/(r-1)}} = \Delta C_o \frac{1-r}{r^{r/(r-1)}}}$$

5.14 The slope = 8/0.0032 = $(E_C - E_T)/2.3k$ = 2500 giving $E_C - E_T$ = 0.5 eV. For the intercept: The plot shows $\tau_e T^2 = 100$ at $1/T = 0.0032 \Rightarrow 1/T = 0$ occurs at $\tau_e T^2$ down by eight decades giving the intercept $= 1/\sigma_n \gamma_n = 10^{-6} \Rightarrow \sigma_n = 10^{-15}$ cm^2.

$$\boxed{E_C - E_T = 0.5 \text{ eV and } \sigma_n = 10^{-15} \text{ cm}^2}$$



5.21 When the impurity is introduced, it is neutral. Since it accepts electrons, it must be an **acceptor**. A donor already has an electron in its neutral state and does not accept any more electrons from the conduction band. The wafer resistivity **increases** since *n* decreases.



[Chapter 6 solution]

6.1 The flatband voltage is $V_{FB} = E_G/2q - \phi_F$, where $\phi_F = (kT/q)\ln(N_A/n_i) = 0.357$ V; $V_{FB} = 0.56-0.357 = 0.203$ V.

$$\frac{C_{FB}}{C_{ox}} = \frac{1}{1+136/1.5\times10^{-6}\times10^{8}} = 0.524$$

Since $\chi(Xx) = \chi(Si)$, therefore $E_c(Xx) = E_c(Si)$ and $V_{FB} = -E_G/2q - \phi_F = -0.56-0.357 = -0.917$ V

$$\boxed{V_{FB}(a) = 0.203\text{ V},\ C_{FB}/C_{ox} = 0.524,\ V_{FB}(b) = -0.917\text{ V}}$$

6.7 (a) At flatband, $C_{lf}/C_{ox} = 1/(1+C_{ox}/C_{lf}) = 1/(1+K_{ox}L_D/K_s t_{ox})$, where the Debye length is $L_D = [kTK_s\varepsilon_o/q^2(p+n)]^{1/2} = [kTK_s\varepsilon_o/q^2 2n_i]^{1/2} \approx 29$ μm in Si at room temperature.
Since $L_D \gg t_{ox}$ we find $C_{lf}/C_{ox} \approx 0$ at flatband. For V_G lower or higher than V_{FB}, the C_{lf}/C_{ox} - V_G curve is symmetrical with respect to $V_G=0$.
(b) The width of the curve decreases slightly.

6.15 $V_T \sim V_{FB}$; $V_{FB} = \phi_{MS} - \dfrac{Q_f}{C_{ox}} - \dfrac{1}{C_{ox}}\displaystyle\int_0^{t_{ox}} \frac{x}{t_{ox}}\rho_{ox}dx$; $\Delta V_T = \Delta V_{FB} = -\dfrac{1}{C_{ox}}\displaystyle\int_0^{t_{ox}}\frac{x}{t_{ox}}\rho_{ox}dx = -\frac{1}{C_{ox}}\frac{t_{ox}}{2}\rho_{ox} = -0.5\ V$

$$\boxed{\rho_{ox} = 0.5\times2\times10^{-8}/10^{-6} = 10^{-2}\ C/cm^3}$$