HW 17.

Thursday, November 19, 2020 7:11 PM

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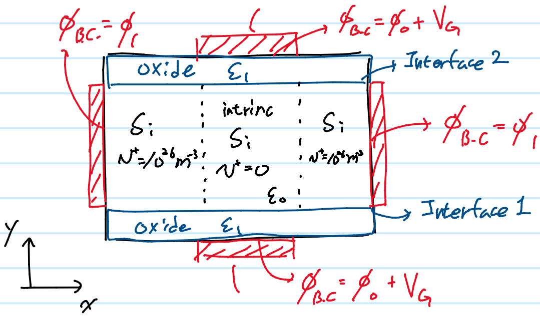
* Scharfetter – Gummel eq. in 1D

$$J_{n,i+\frac{1}{2}} = \frac{q D_n}{\Delta x}\left[n_{i+1} B\left(\frac{\phi_{i+1}-\phi_i}{V_T}\right) - n_i B\left(\frac{\phi_i-\phi_{i+1}}{V_T}\right)\right] = \frac{\delta J_{n(i+1,i)}}{\delta x}$$

$$B(x) = \frac{x}{e^x-1}, \quad \frac{dB(x)}{dx} = \frac{e^x-1-xe^x}{(e^x-1)^2}$$



Hw 10. 에서는 $N_{acc}=10^{26}m^{-3}$ 로 두었지만, Hw 17. 에선 $N^+=-N_{acc}=10^{26}m^{-3}$ 으로 하였다.

: Interface 에서 density는 0이다.

In 2D, $\vec{\nabla}\cdot\vec{J}_n = 0$,

i) Bulk

$$\int_v \nabla\cdot\vec{J}_n\, dz = \int_s \vec{J}_n\cdot d\vec{a} = 0$$

$i,j+1$ $\quad i-1,j \quad i,j \quad i+1,j$ $\quad i,j-1$

$$\Rightarrow \Delta\left(J_{n(i,j+\frac{1}{2})} + J_{n(i+\frac{1}{2},j)} - J_{n(i-\frac{1}{2},j)} - J_{n(i,j-\frac{1}{2})}\right) = 0 \quad (\Delta\text{는 grid spacing})$$

$$\Rightarrow \delta J_{n(i,j+1;i,j)} + \delta J_{n(i+1,j;i,j)} - \delta J_{n(i,j;i-1,j)} - \delta J_{n(i,j;i,j-1)} = 0$$

$$\therefore [R_n]_{i,j} = \begin{cases} \delta J_{n(i,j+1;i,j)} + \delta J_{n(i+1,j;i,j)} - \delta J_{n(i,j;i-1,j)} - \delta J_{n(i,j;i,j-1)} & \text{in silicon} \\ n_{i,j} & \text{in oxide} \end{cases}$$

For Poisson eq.,

$$[R_\phi]_{i,j} = \varepsilon(-4\phi_{i,j} + \phi_{i+1,j} + \phi_{i-1,j} + \phi_{i,j+1} + \phi_{i,j-1}) - \Delta^2 q(-N^+ + n_{i,j})$$

$$\therefore \begin{cases} \partial_{\phi_{i,j}}[R_\phi]_{i,j} = -4\varepsilon, \quad \partial_{\phi_{i+1,j}}[R_\phi]_{i,j} = \partial_{\phi_{i-1,j}}[R_\phi]_{i,j} = \partial_{\phi_{i,j+1}}[R_\phi]_{i,j} = \partial_{\phi_{i,j-1}}[R_\phi]_{i,j} = \varepsilon \\ \partial_{n_i}[R_\phi]_{i,j} = -\Delta^2 q \end{cases}$$

In silicon

$$\begin{cases} \partial_{\phi_{i,j}}[R_n]_{i,j} = qD_n\Big[n_{i,j+1}\partial_{\phi_{i,j}}B\left(\frac{\phi_{i,j+1}-\phi_{i,j}}{V_T}\right) - n_{i,j}\partial_{\phi_{i,j}}B\left(\frac{\phi_{i,j}-\phi_{i,j+1}}{V_T}\right) + n_{i+1,j}\partial_{\phi_{i,j}}B\left(\frac{\phi_{i+1,j}-\phi_{i,j}}{V_T}\right) - n_{i,j}\partial_{\phi_{i,j}}B\left(\frac{\phi_{i,j}-\phi_{i+1,j}}{V_T}\right) \\ \qquad - n_{i,j}\partial_{\phi_{i,j}}B\left(\frac{\phi_{i,j}-\phi_{i-1,j}}{V_T}\right) + n_{i-1,j}\partial_{\phi_{i,j}}B\left(\frac{\phi_{i-1,j}-\phi_{i,j}}{V_T}\right) - n_{i,j}\partial_{\phi_{i,j}}B\left(\frac{\phi_{i,j}-\phi_{i,j-1}}{V_T}\right) + n_{i,j-1}\partial_{\phi_{i,j-1}}B\left(\frac{\phi_{i,j-1}-\phi_{i,j}}{V_T}\right)\Big] \\ \partial_{\phi_{i,j+1}}[R_n]_{i,j} = \partial_{\phi_{i,j+1}}\left(\delta J_{n(i,j+1;i,j)}\right), \quad \partial_{\phi_{i+1,j}}[R_n]_{i,j} = \partial_{\phi_{i+1,j}}\left(\delta J_{n(i+1,j;i,j)}\right) \\ \partial_{\phi_{i-1,j}}[R_n]_{i,j} = -\partial_{\phi_{i-1,j}}\left(\delta J_{n(i,j;i-1,j)}\right), \quad \partial_{\phi_{i,j-1}}[R_n]_{i,j} = -\partial_{\phi_{i,j-1}}\left(\delta J_{n(i,j;i,j-1)}\right) \end{cases}$$

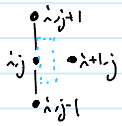
In silicon

$$\begin{cases} \partial_{n_{i,j}}[R_n]_{i,j} = qD_n\left[-B\left(\frac{\phi_{i,j}-\phi_{i,j+1}}{V_T}\right) - B\left(\frac{\phi_{i,j}-\phi_{i+1,j}}{V_T}\right) + B\left(\frac{\phi_{i-1,j}-\phi_{i,j}}{V_T}\right) + B\left(\frac{\phi_{i,j-1}-\phi_{i,j}}{V_T}\right)\right] \\ \partial_{n_{i,j+1}}[R_n]_{i,j} = qD_n\left[B\left(\frac{\phi_{i,j+1}-\phi_{i,j}}{V_T}\right)\right], \quad \partial_{n_{i+1,j}}[R_n]_{i,j} = qD_n\left[B\left(\frac{\phi_{i+1,j}-\phi_{i,j}}{V_T}\right)\right] \\ \partial_{n_{i-1,j}}[R_n]_{i,j} = qD_n\left[B\left(\frac{\phi_{i-1,j}-\phi_{i,j}}{V_T}\right)\right], \quad \partial_{n_{i,j-1}}[R_n]_{i,j} = qD_n\left[B\left(\frac{\phi_{i,j-1}-\phi_{i,j}}{V_T}\right)\right] \end{cases}$$

In Oxide $\partial_{n_{i,j}}[R_n]_{i,j} = 1$.

ii) Edge

Homogeneous Neumann B.C.,

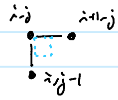


$[R_n]_{i,j} = n_{i,j}$ or $n_{i,j} - N^+$ (silicon layer 에서만)

$[R_\phi]_{i,j} = \varepsilon\left(-2\phi_{i,j} + \phi_{i+1,j} + \frac{1}{2}\phi_{i,j+1} + \frac{1}{2}\phi_{i,j-1}\right)$

$\therefore\ \partial_{\phi_{i,j}}[R_\phi]_{i,j} = -2\varepsilon$, $\partial_{\phi_{i+1,j}}[R_\phi]_{i,j} = \varepsilon$, $\partial_{\phi_{i,j+1}}[R_\phi]_{i,j} = \partial_{\phi_{i,j-1}}[R_\phi]_{i,j} = \frac{1}{2}\varepsilon$

$\partial_{n_{i,j}}[R_n]_{i,j} = 1$.



$[R_n]_{i,j} = n_{i,j}$

$[R_\phi]_{i,j} = \varepsilon\left(-\phi_{i,j} + \frac{1}{2}\phi_{i+1,j} + \frac{1}{2}\phi_{i,j-1}\right)$

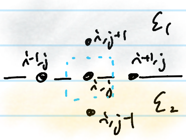
$\therefore\ \partial_{\phi_{i,j}}[R_\phi]_{i,j} = -\varepsilon$, $\partial_{\phi_{i+1,j}}[R_\phi]_{i,j} = \partial_{\phi_{i,j-1}}[R_\phi]_{i,j} = \frac{\varepsilon}{2}$

$\partial_{n_{i,j}}[R_n]_{i,j} = 1$.

Dirichlet B.C.

$[R_\phi]_{i,j} = \phi_{i,j} - \phi_{B.C.}$, $[R_n]_{i,j} = n_{i,j} - N^+$

iii) Interface



$[R_n]_{i,j} = n_{i,j}$

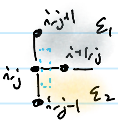
$[R_\phi]_{i,j} = -2(\varepsilon_1+\varepsilon_2)\phi_{i,j} + \frac{\varepsilon_1+\varepsilon_2}{2}\phi_{i+1,j} + \frac{\varepsilon_1+\varepsilon_2}{2}\phi_{i-1,j} + \varepsilon_1\phi_{i,j+1} + \varepsilon_2\phi_{i,j-1}$
$\quad - \Delta^2 q\left(-N^+ + n_{i,j}\right)$

$\therefore\ \partial_\phi[R_n]_{i,j}$ 와 $\partial_n[R_n]_{i,j}$는 i)과 동일.

$\partial_{\phi_{i,j}}[R_\phi]_{i,j} = -2(\varepsilon_1+\varepsilon_2)$, $\partial_{\phi_{i+1,j}}[R_\phi]_{i,j} = \partial_{\phi_{i-1,j}}[R_\phi]_{i,j} = \frac{\varepsilon_1+\varepsilon_2}{2}$

$\partial_{\phi_{i,j+1}}[R_\phi]_{i,j} = \varepsilon_1$, $\partial_{\phi_{i,j-1}}[R_\phi]_{i,j} = \varepsilon_2$

$\partial_{n_{i,j}}[R_\phi]_{i,j} = -\Delta^2 q$



$[R_n]_{i,j} = n_{i,j}$

$[R_\phi]_{i,j} = -(\varepsilon_1+\varepsilon_2)\phi_{i,j} + \frac{(\varepsilon_1+\varepsilon_2)}{2}\phi_{i+1,j} + \frac{\varepsilon_1}{2}\phi_{i,j+1} + \frac{\varepsilon_2}{2}\phi_{i,j-1}$

$\partial_\phi[R_n]_{i,j}$ 와 $\partial_n[R_n]_{i,j}$는 ii)과 동일.

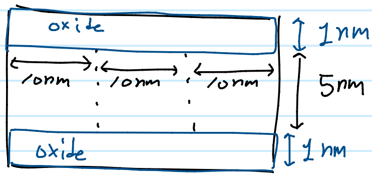
$\partial_{\phi_{i,j}}[R_\phi]_{i,j} = -(\varepsilon_1+\varepsilon_2)$, $\partial_{\phi_{i+1,j}}[R_\phi]_{i,j} = \frac{\varepsilon_1+\varepsilon_2}{2}$

$\partial_{\phi_{i,j+1}}[R_\phi]_{i,j} = \frac{\varepsilon_1}{2}$, $\partial_{\phi_{i,j-1}}[R_\phi]_{i,j} = \frac{\varepsilon_2}{2}$

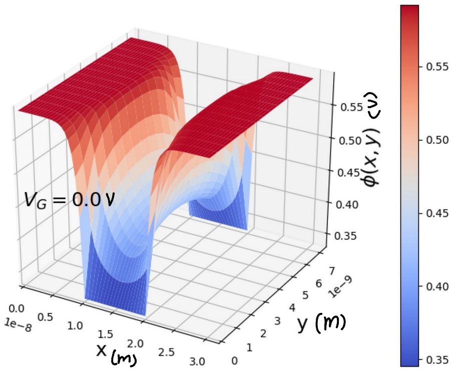
* Algorithm은 HW15. 와 동일

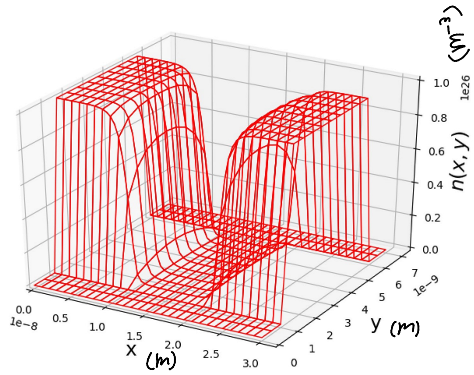
Results.

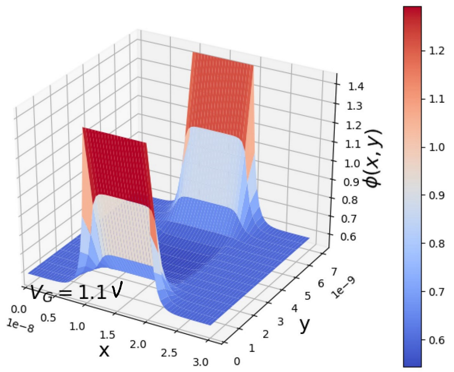
$\Delta = 0.5\,nm,\ L_x = 30\,nm,\ L_y = 7\,nm$

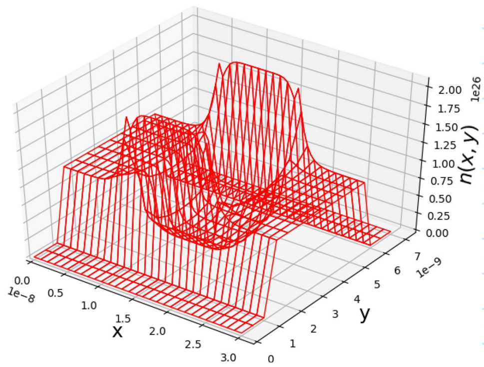


1) $\phi(x,y)$ & $n(x,y)$ with Hw 10. method.

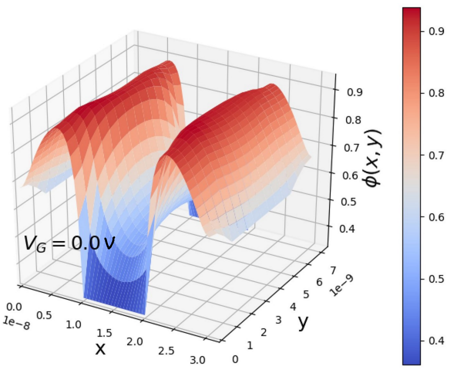


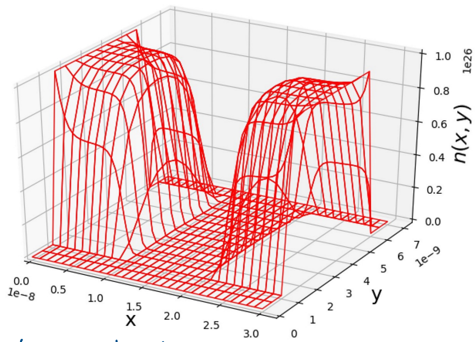




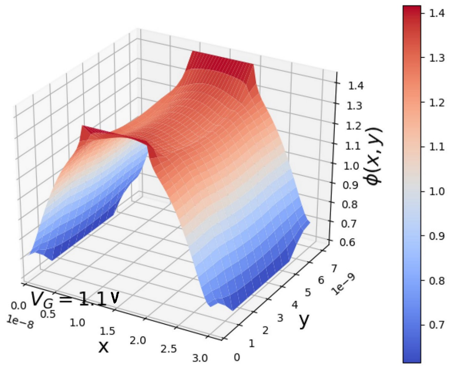


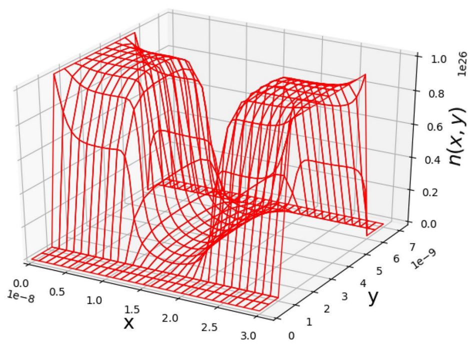
2) $\phi(x,y)$ & $n(x,y)$ with Hw 11. method at $V_D = 0V$



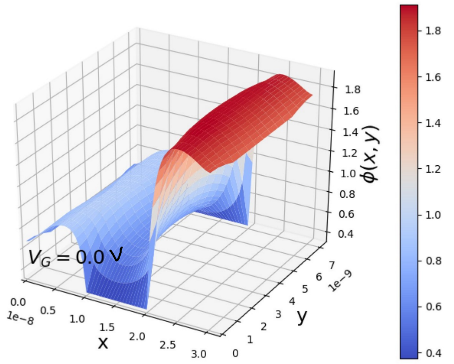


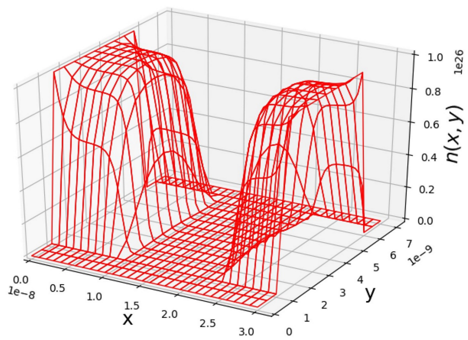
Hw 10.과 꽤 다르다.



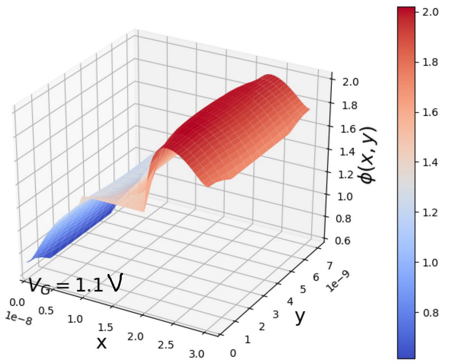


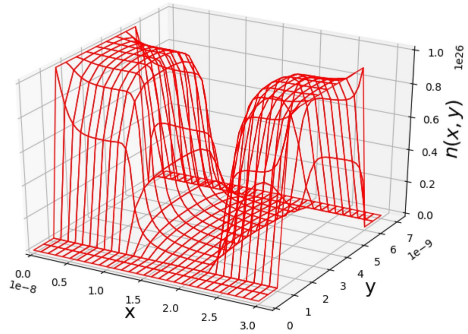
3) $\phi(x,y)$ & $n(x,y)$ with HW17 method at $V_D = 1.1V$





Density는 거의 변화가 없다.

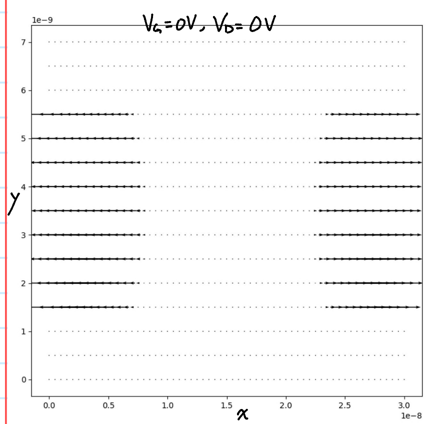




4) I_D or I_S vs. V_D

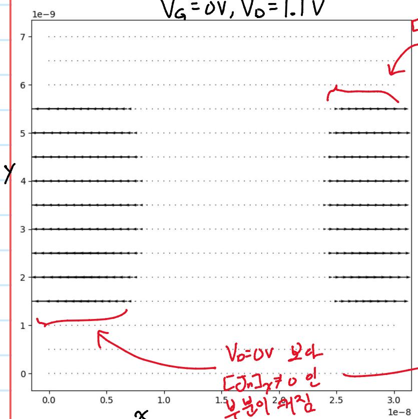
$\mu = 1500\ cm^2/V\cdot s$. 먼저 $[J_n]_{x\text{-dir.}}$ 를 xy-plane 에서 보자.

$V_G = 0V,\ V_D = 0V$



Source 나 Drain 근처에서 $\phi(x,y)$가 감소하는 영역이 $[J_n]_x \neq 0$인 영역임을 알 수 있다.

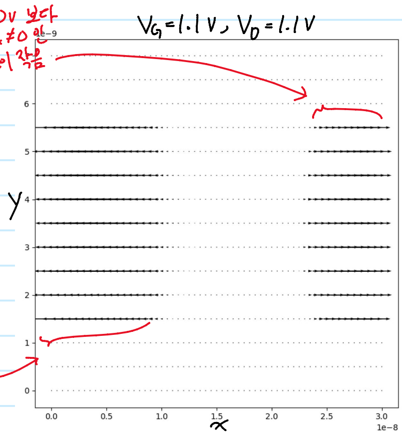
$V_G = 0V,\ V_D = 1.1V$

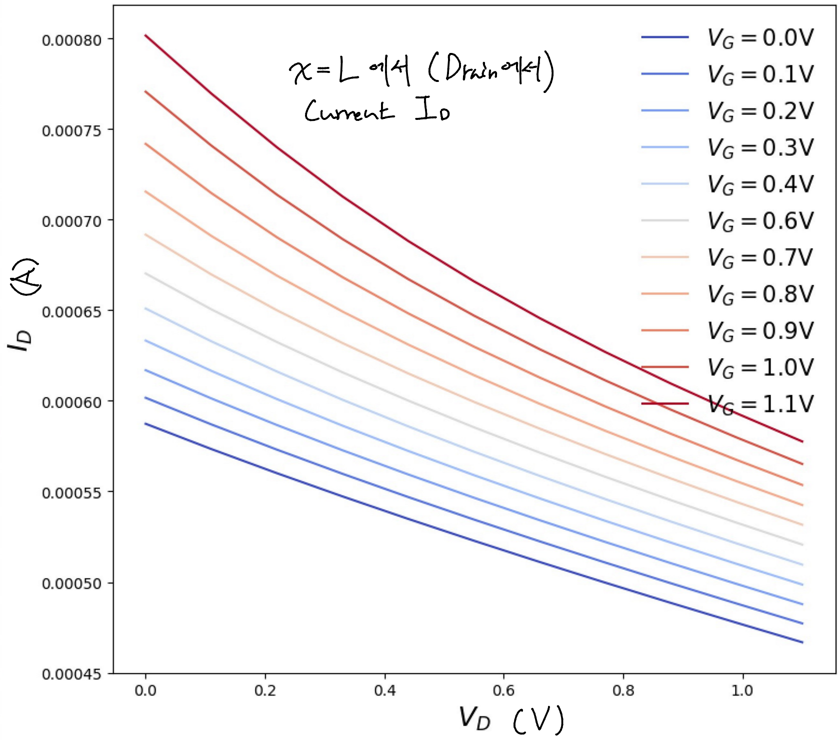


$V_D = 0V$ 보다 $[J_n]_x \neq 0$ 인 부분이 작음

$V_D = 0V$ 보다 $[J_n]_x \neq 0$ 인 부분이 커짐

$V_G = 1.1V,\ V_D = 1.1V$





V_D를 올릴 수록 I_D가 작아지는 결론이 나왔다. $\phi_{(x,y)}$의 경향과 잘 부합하는 결과이다.