HW 6.

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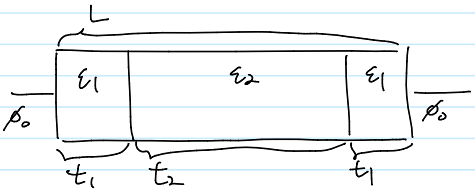
20184060 Jicheol Kim



$\frac{d}{dx}\left(\varepsilon(x)\frac{d\phi(x)}{dx}\right) = b(x)$ 에서,

$$\varepsilon(x) = \begin{cases} \varepsilon_1 & \text{for } 0 \le x < t_1 \\ \varepsilon_2 & \text{for } t_1 \le x < t_1+t_2 \\ \varepsilon_1 & \text{for } t_1+t_2 \le x < L \end{cases}, \quad b(x) = \begin{cases} \phi_0 & \text{at } x=0 \\ 0 & \text{for } 0<x<t_1 \\ qN_{acc} & \text{for } t_1<x<t_1+t_2 \\ 0 & \text{for } t_1+t_2<x<L \\ \phi_0 & \text{at } x=L \end{cases}$$

when we take the depletion approximation.

$\phi(0) = \phi(L) = 0$.

If we add an electron (hole) density to the $b(x)$ of the depletion approximation,

$$b(x) = \begin{cases} \phi_0 + V_G & \text{at } x=0 \\ 0 & \text{for } 0<x<t_1 \\ qN_{acc} + q(n(x)-p(x)) & \text{for } t_1<x<t_1+t_2 \\ 0 & \text{for } t_1+t_2<x<L \\ \phi_0+V_G & \text{at } x=L \end{cases}$$

where V_G is a gate voltage, $n(x)$ ($p(x)$) is an electron (hole) density.

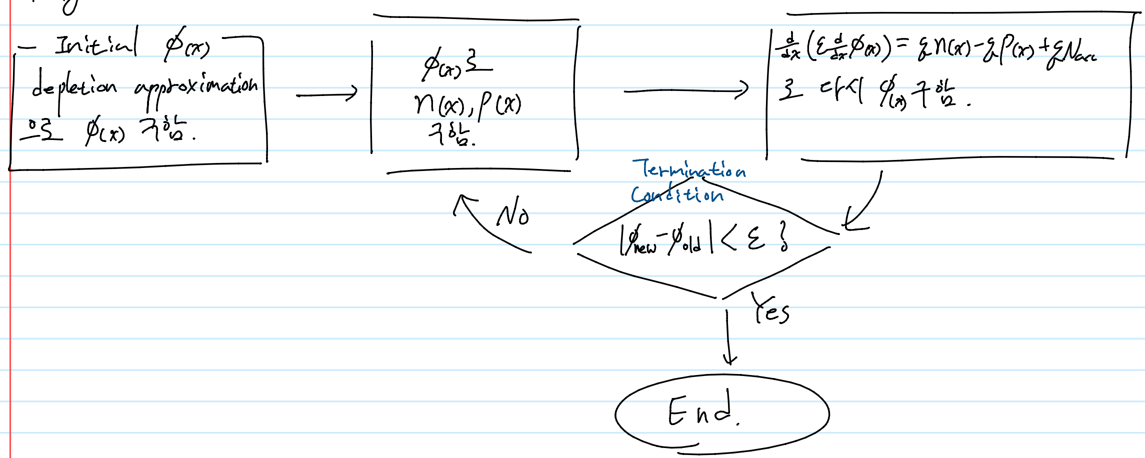
$$\begin{cases} n(x) = N_c \exp\left(-\frac{E_c-E_i}{k_BT}\right)\exp\left(\frac{q\phi}{k_BT}\right) \\ p(x) = N_c \exp\left(-\frac{E_c-E_i}{k_BT}\right)\exp\left(-\frac{q\phi}{k_BT}\right) \end{cases} \Rightarrow q(n(x)-p(x)) = 2qN_c e^{-\frac{E_c-E_i}{k_BT}}\cosh\left(\frac{q\phi}{k_BT}\right)$$

By finite difference,

$$\frac{d}{dx}\left(\varepsilon(x)\frac{d}{dx}\right) \rightarrow A = \begin{pmatrix} 1 & 0 & \cdots & & & & & & & \\ \varepsilon_1 & -2\varepsilon_1 & \varepsilon_1 & & & & & 0 & & \\ & \ddots & & & & & & & & \\ & & \varepsilon_1 & -2\varepsilon_1 & \varepsilon_1 & & & & & \\ & & & \varepsilon_1 & -\varepsilon_1-\varepsilon_2 & \varepsilon_2 & & & & \\ & & & & \varepsilon_2 & -2\varepsilon_2 & \varepsilon_2 & & & \\ & & & & & \ddots & & & & \\ & & & & & \varepsilon_2 & -2\varepsilon_2 & \varepsilon_2 & & \\ & & & & & & \varepsilon_2 & -\varepsilon_1-\varepsilon_2 & \varepsilon_1 & \\ & 0 & & & & & & \varepsilon_1 & -2\varepsilon_1 & \varepsilon_1 \\ & & & & & & & & \ddots & \\ & & & & & & & \varepsilon_1 & -2\varepsilon_1 & \varepsilon_1 \\ & & & & & & & \cdots & 0 & 1 \end{pmatrix}$$

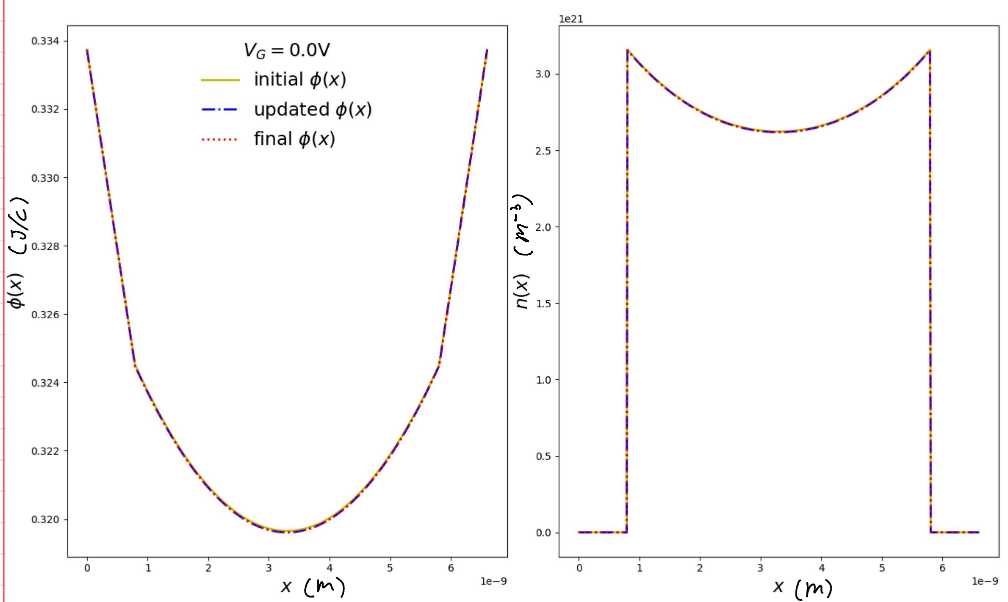
$$
b(x) = (\Delta x)^2 \begin{pmatrix} \phi_0 + V_G \\ \vdots \\ 0 \\ \frac{q N_{acc}}{2} \\ q N_{acc} + q(n(x) - p(x)) \\ \vdots \\ q N_{acc} + q(n(x) - p(x)) \\ \frac{q N_{acc}}{2} \\ 0 \\ \vdots \\ \phi_0 + V_G \end{pmatrix}
\begin{array}{l} \\ \\ \\ \to x = t_1 \\ \\ \\ \\ \to x = t_1 + t_2 \\ \\ \\ \\ \end{array}
, \quad \phi(x) = \begin{pmatrix} \phi_1 \\ \vdots \\ \phi_N \end{pmatrix}
$$

* Algorithm.

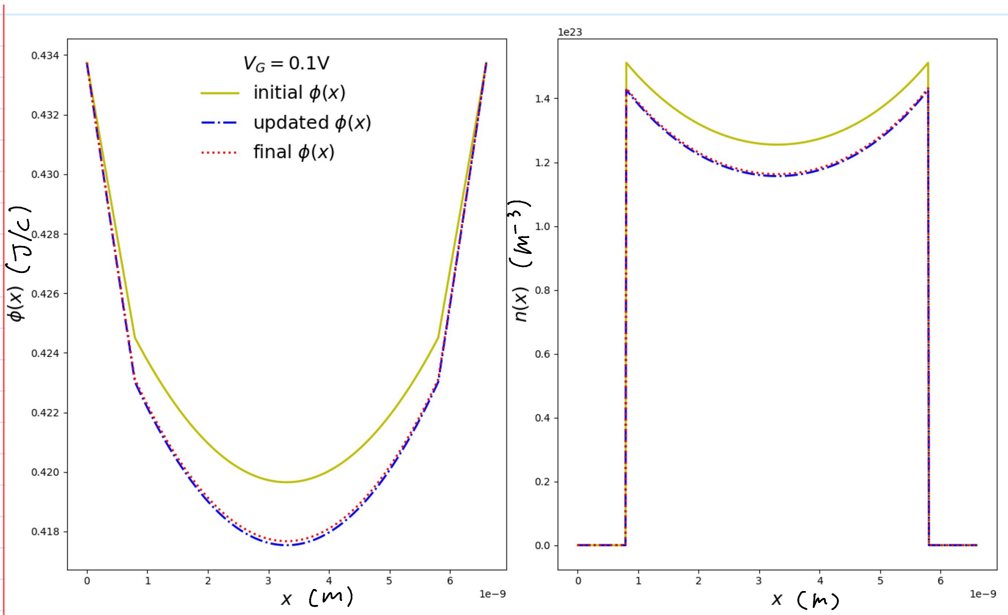


Results.

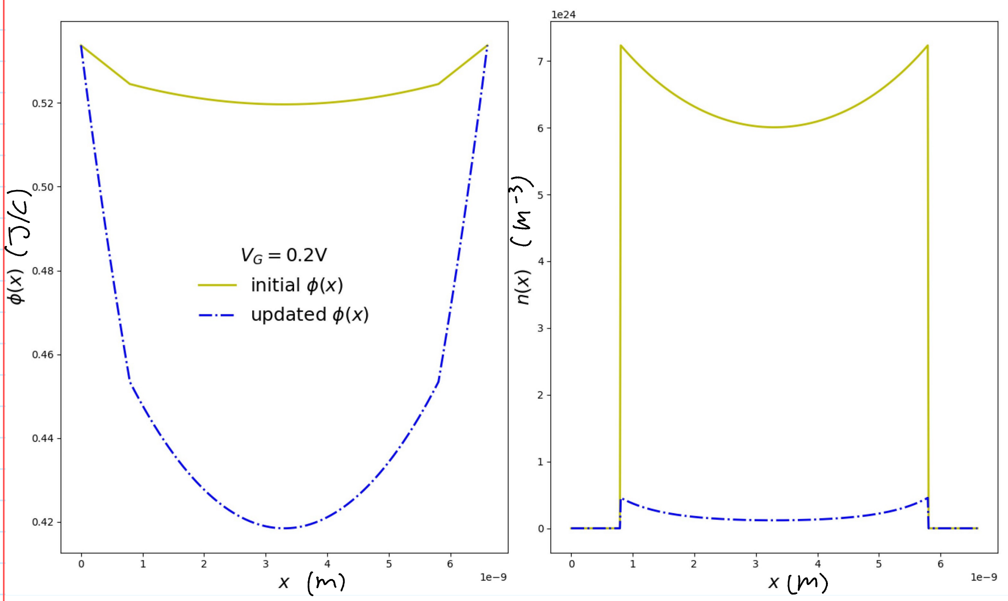
$\phi_0 = 0.33374\,V$, $N = 500$, $N_{acc} = 10^{24}\ m^{-3}$,
$t_1 = 0.8\ nm$, $t_2 = 5\ nm$, $\varepsilon_1 = 3.9\varepsilon_0$, $\varepsilon_2 = 11.7\varepsilon_0$, $T = 300K$.



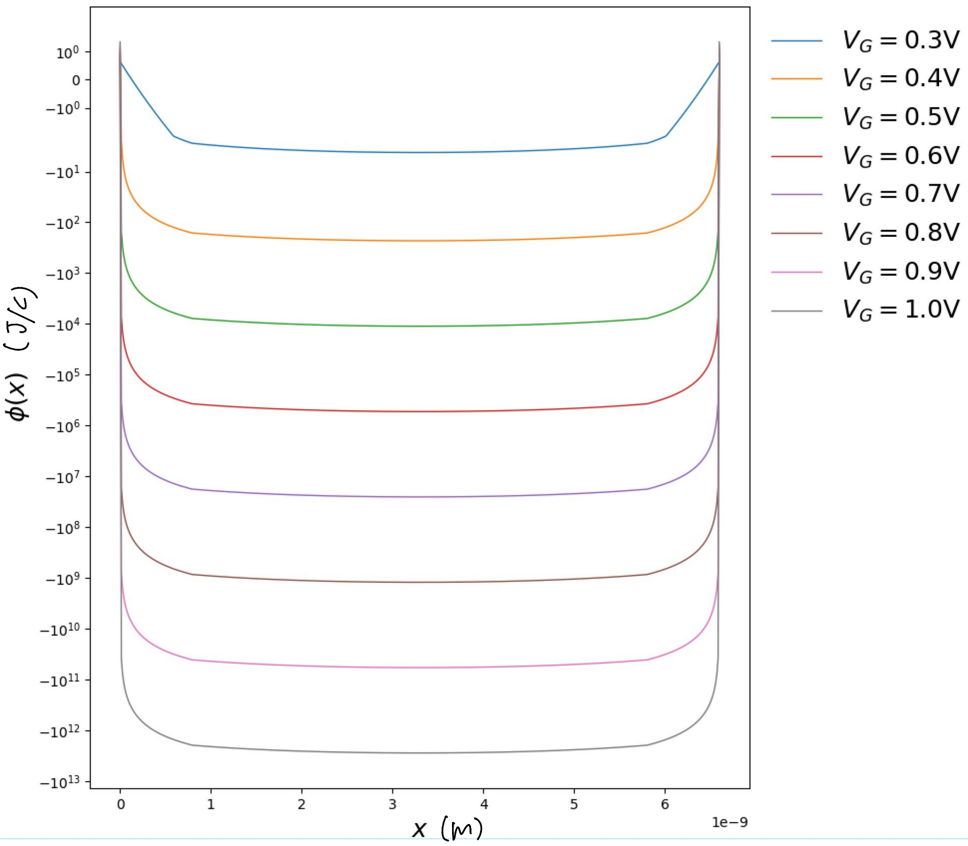
Updated 는 loop를 1번만 거쳤을 때, final 은 termination 후, $\phi(x)$ 이다.
$V_G = 0V$ 면, $N_{acc} \gg n(x)$ 이기 때문에 $\phi_{init.}(x) \simeq \phi_{final}(x)$ 이다.



$V_G = 0.1V$ 경우 $\phi(x)$가 잘 수렴한다. 아직 $N_{acc} \gg n(x)$이기 때문으로 보여진다.



$V_G = 0.2V$ 에선 $N_{acc} \lesssim n(x)$가 된다. 이 때문에 loop는 진행하면,
$\phi(x)$ 값이 진동하면서 수렴하지 않는다.
$V_G > 0.2V$ 부터는 $N_{acc} \ll n(x)$가 되면서 loop를 진행하게 되면,
$b(x)$가 발산하여 $\phi(x)$가 수렴하지 않는다.



log scale로 $\phi_{updated}(x)$를 그려보면 V_G가 0.3 V 이상에서 $\phi(\frac{L}{2})$이 log scale로 증가함을 알 수 있다.