# Meshing

Let start_SC be the point at interface but a little towards oxide.

## Across oxide

1. *start_SC* points in oxide width

$$\Delta x[i] = i \cdot \frac{t_{ox}}{start\_SC}, \quad i = 0, 1, 2, \ldots, start\_SC$$

## Across oxide

2. Remaining points in semiconductor so that spacing between then is like $c_x b_x^i$

$$\Delta x[i] = t_{ox} + c_x \frac{(pow(b_x, (i - start\_SC)) - 1)}{(b_x - 1)}$$

# Step2: Poission equation solving

$$\frac{d}{dx}\left(\epsilon\frac{dV}{dx}\right) = -\rho \tag{1}$$

$$\frac{\epsilon_{i+0.5}(V_{i+1} - V_i) - \epsilon_{i-0.5}(V_i - V_{i-1})}{\Delta x^2} = -\rho_i \tag{2}$$

# Step3: Carrier concentation equation solving :

$$J_n = \mu_n nqE + qD_n \frac{dn}{dx} \tag{3}$$

$$J_p = \mu_p pqE - qD_p \frac{dp}{dx} \tag{4}$$

$$\frac{dn}{dt} = \frac{1}{q}\frac{\partial J_n}{\partial x} - \frac{n - n_{eq}}{\tau_n} \tag{5}$$

$$\frac{dp}{dt} = -\frac{1}{q}\frac{\partial J_p}{\partial x} - \frac{p - p_{eq}}{\tau_p} \tag{6}$$

# Step4: Solving Carrier continuity in 3 steps:

- Solve in equilibrium conditions
- In DC bias
- AC conditions

# Step 4.1: equilibrium conditions

$$\frac{\partial n}{\partial t} = \frac{\partial p}{\partial t} = 0 \tag{7}$$

$$\frac{\partial J_n}{\partial x} = \frac{\partial J_p}{\partial x} = 0 \tag{8}$$

$$\tag{9}$$

generation and recombination balance each other, hence

$$J_{i-0.5} = J_{i+0.5} \tag{10}$$

By applying Scharfetter-Gummel,

$$\frac{n_{i+1}B(\phi_{i+1} - \phi_i) - n_i B(\phi_i - \phi_{i+1})}{\Delta x_i} = \frac{n_i B(\phi_i - \phi_{i-1}) - n_{i-1}B(\phi_i - \phi_{i-1})}{\Delta x_{i-1}} \tag{11}$$

It can be written as,

$$\alpha_{i-1}n_{i-1} + \alpha_i n_i + \alpha_{i+1}n_{i+1} = 0 \tag{12}$$

$$\tag{13}$$

# Step 4.2 : DC bias

system is in steady state,

$$\frac{\partial p}{\partial t} = \frac{\partial n}{\partial t} = 0 \tag{14}$$

$$\implies \frac{1}{q}\frac{J_{n(i+\frac{1}{2})} - J_{n(i-\frac{1}{2})}}{\Delta x_{i-\frac{1}{2}}} - \frac{n}{\tau_n} + \frac{n_{eq}}{\tau_n} = 0 \tag{15}$$

$$\frac{1}{q}\frac{J_{p(i-\frac{1}{2})} - J_{p(i+\frac{1}{2})}}{\Delta x_{i-\frac{1}{2}}} - \frac{p}{\tau_p} + \frac{p_{eq}}{\tau_p} = 0 \tag{16}$$

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Again after applying Scharfetter-Gummel,

$$\alpha_{i-1} n_{i-1} + \alpha_i n_i + \alpha_{i+1} n_{i+1} = -\frac{n_{eqi}}{\tau_n} \tag{18}$$

$$\beta_{i-1} p_{i-1} + \beta_i p_i + \beta_{i+1} p_{i+1} = -\frac{p_{eqi}}{\tau_p} \tag{19}$$

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# Step 4.3 : AC anaylsis

$$J_n = \mu_n nqE + qD_n \frac{dn}{dx} \tag{21}$$

$$J_p = \mu_p pqE - qD_p \frac{dp}{dx} \tag{22}$$

After applying Crank Nicolson,

$$\frac{{n_i}^{j+1} - {n_i}^j}{\Delta t} = \frac{1}{2}\left(\frac{1}{q}\left[\frac{\partial J_n}{\partial x}\right]^{j+1} + G_n^{j+1} - R_n^{j+1} + \frac{1}{q}\left[\frac{\partial J_n}{\partial x}\right]^j + G_n^j - R_n^j\right) \tag{23}$$

After rearranging the terms, we come to a equations of this form,

$$\alpha_{i-1} n_{i-1} + \alpha_i n_i + \alpha_{i+1} n_{i+1} + c_1 = 0 \tag{24}$$

$$\beta_{i-1} p_{i-1} + \beta_i p_i + \beta_{i+1} p_{i+1} + c_2 = 0 \tag{25}$$

# Boundary Conditions for n,p

Near oxide-semiconductor interface there is no current in oxide, and applying Scharfetter-Gummel Discretization

$$J_{i+\frac{1}{2}} = J_{i-\frac{1}{2}} = 0 \tag{26}$$

$$\implies n_i = \frac{n_{i+1}}{exp(\phi_{i+1} - \phi_i)} \tag{27}$$

$$p_i = p_{i+1} exp(\phi_{i+1} - \phi_i) \tag{28}$$

# Iterative Solution Process

The solution proceeds iteratively in two steps until convergence is reached:

- **Initial Guess for Voltage ($V$):** Start with an initial guess for the voltage across the device.
- **Poisson Equation Solver:** Solve the Poisson equation to update the voltage $V$.
- **Carrier Continuity Equation:** Solve the carrier continuity equations for electron ($n$) and hole densities ($p$) at equilibrium then dc then ac.
- **Convergence Check:** Compare the updated values of $V$, $n$, and $p$ with their previous values. If the difference is smaller than a predefined threshold, the process converges.

# Step6 : Capacitance in term of Q and V

$$C = \frac{dQ}{dV_G} = \epsilon_{ox} \frac{\frac{d\mathcal{E}_{ox}}{dt}}{\frac{dV_G}{dt}} \tag{29}$$

$$= \epsilon_{ox} \frac{\mathcal{E}_{ox}(t_{i+1}) - \mathcal{E}_{ox}(t_i)}{V_G(t_{i+1}) - V_G(t_i)} \tag{30}$$

$$= \epsilon_{ox} \frac{(V(0, t_{i+1}) - V(x_1, t_{i+1})) - (V(0, t_i) - V(x_1, t_i))}{(V_G(t_{i+1}) - V_G(t_i))\,\Delta x_1} \tag{31}$$

$$= \frac{\epsilon_{ox}}{\Delta x_1} \left(1 - \frac{V(x_1, t_{i+1}) - V(x_1, t_i)}{V_G(t_{i+1}) - V_G(t_i)}\right) \tag{32}$$