Computational Microelectronics
Lecture 17 Continuity Equation

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Continuity Equation

Jacobian

- From the following expression,

$$J_n(x_{i+0.5}) = \frac{qD_n}{x_{i+1}-x_i}\left[(n_{i+1}-n_i) - \frac{1}{V_T}\frac{n_{i+1}+n_i}{2}(\phi_{i+1}-\phi_i)\right]$$

  - Components of Jacobian matrix are given as

$$\frac{\partial J_n(x_{i+0.5})}{\partial n_{i+1}} = \frac{qD_n}{x_{i+1}-x_i}\left[1 - \frac{\phi_{i+1}-\phi_i}{2V_T}\right]$$

$$\frac{\partial J_n(x_{i+0.5})}{\partial n_i} = \frac{qD_n}{x_{i+1}-x_i}\left[-1 - \frac{\phi_{i+1}-\phi_i}{2V_T}\right]$$

$$\frac{\partial J_n(x_{i+0.5})}{\partial \phi_{i+1}} = \frac{qD_n}{x_{i+1}-x_i}\left[-\frac{n_{i+1}+n_i}{2V_T}\right]$$

$$\frac{\partial J_n(x_{i+0.5})}{\partial \phi_i} = \frac{qD_n}{x_{i+1}-x_i}\left[\frac{n_{i+1}+n_i}{2V_T}\right]$$

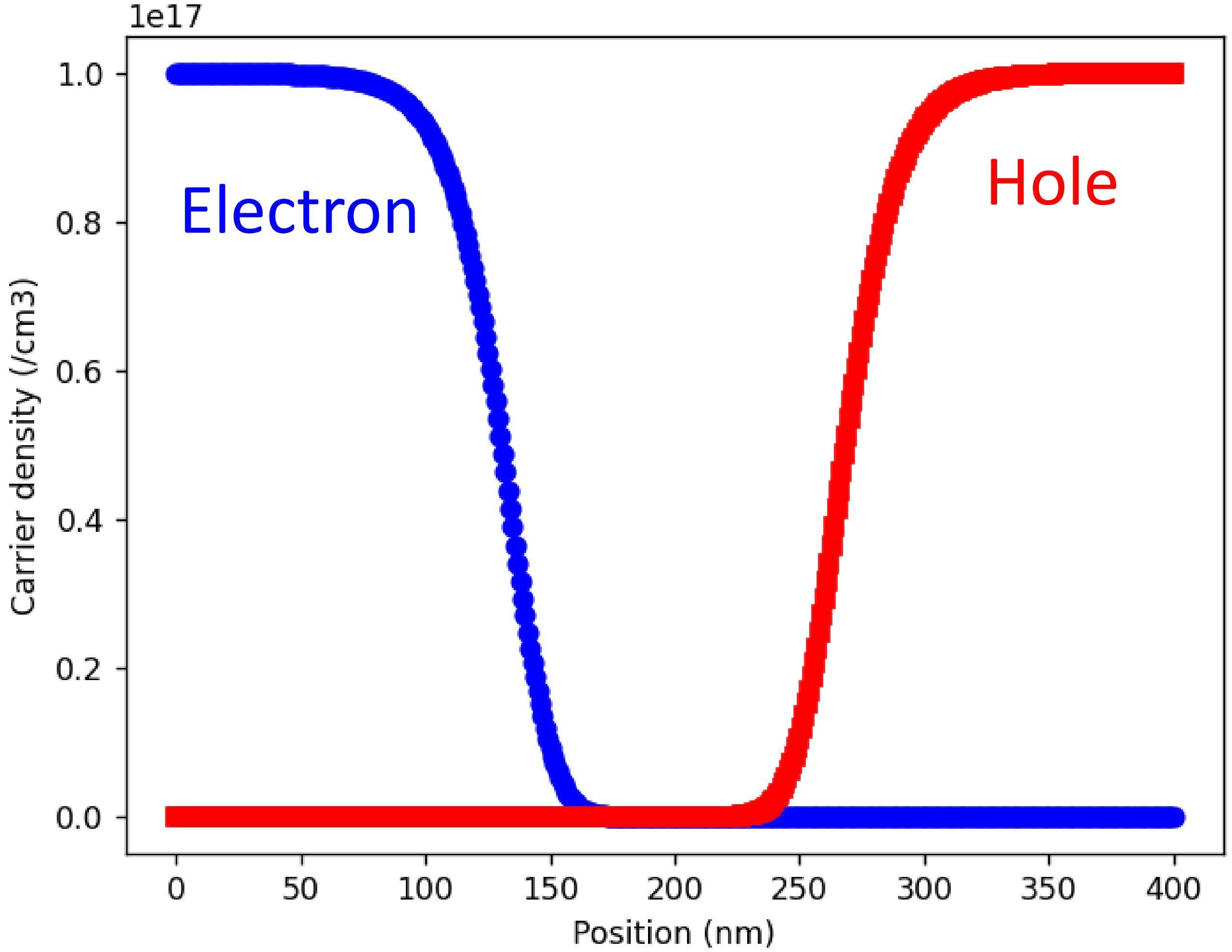
Arranging variables & boundary condition

- Three variables (ϕ, n, and p) at each vertex
  - $3i$ for potential, $3i+1$ for electrons, $3i+2$ for holes
  - Carrier densities are fixed at two boundaries.

$$\begin{bmatrix} \text{Poisson} \\ \text{Electron continuity} \\ \text{Hole continuity} \\ \text{Poisson} \\ \text{Electron continuity} \\ \text{Hole continuity} \\ \dots \\ \end{bmatrix} \text{X} \begin{bmatrix} \delta\phi \\ \delta n \\ \delta p \\ \delta\phi \\ \delta n \\ \delta p \\ \vdots \end{bmatrix} = \begin{bmatrix} r_\phi \\ r_n \\ r_p \\ r_\phi \\ r_n \\ r_p \\ \vdots \end{bmatrix}$$

Equilibrium

- $N_D = N_A = 10^{17}$ cm^{-3}. 1-nm spacing



HW#14

- Due: AM08:00, November 13
- Problem#1
  - In the previous HW#13, three PN junctions were simulated with the nonlinear Poisson equation.
  - In this problem, using the drift-diffusion simulator you implemented, simulate the same devices.

Bias Ramping

Bias ramping

- We start from the equilibrium solution at 0 V
  - Increase the anode voltage (Forward)
  - Decrease the anode voltage (Reverse)
  - Boundary condition for the cathode contact

$$r_0 = \phi(x_0) - \phi_0\left(N_{dop}^{+}(x_0)\right)$$
$$A_{0,0} = 1$$

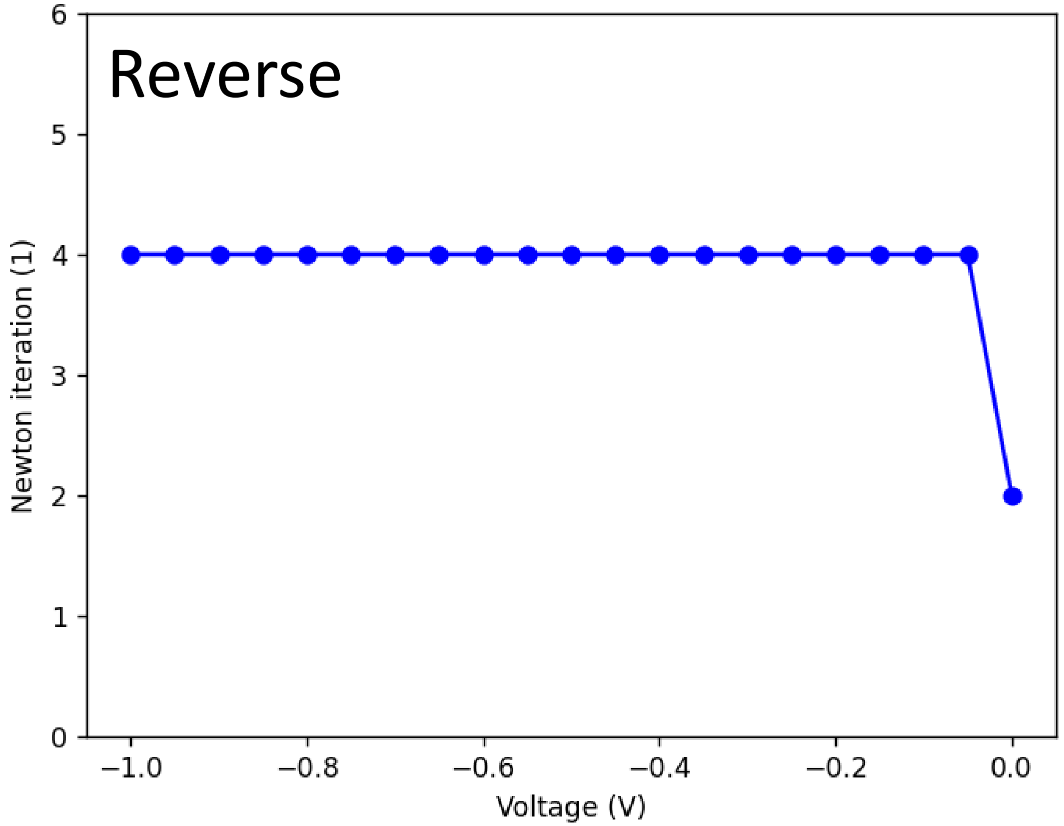
  - Boundary condition for the anode contact

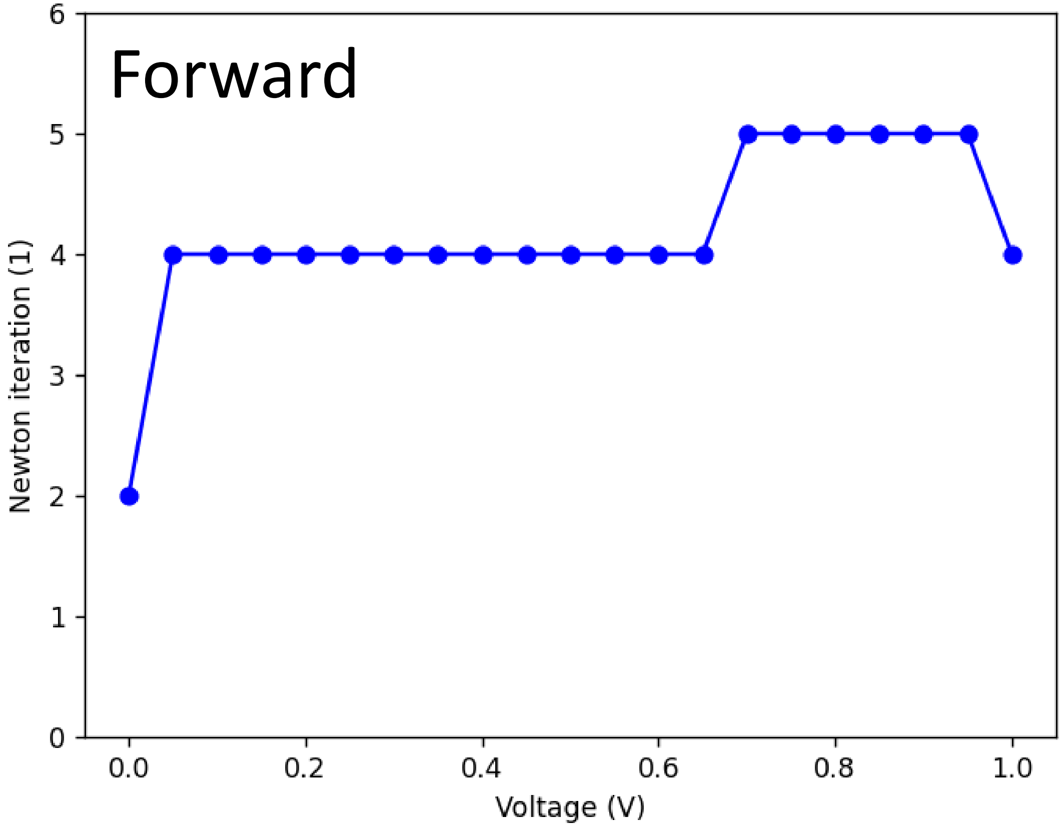
$$r_{3N} = \phi(x_N) - \phi_0\left(N_{dop}^{+}(x_N)\right) - V_{anode}$$
$$A_{3N,3N} = 1$$

Equilibrium potential

Number of Newton iterations

- Convergence criterion of 10-10 V
  - We need 4~5 iterations at each bias point.





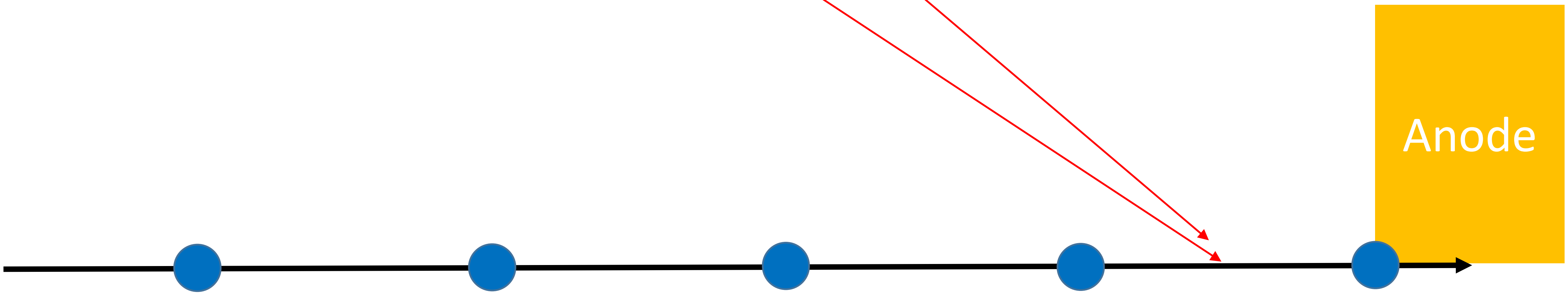
Terminal current

- In a steady-state,

$$I_{terminal} = -\int_{terminal\ area} (\mathbf{J}_p + \mathbf{J}_n) \cdot d\mathbf{a}$$

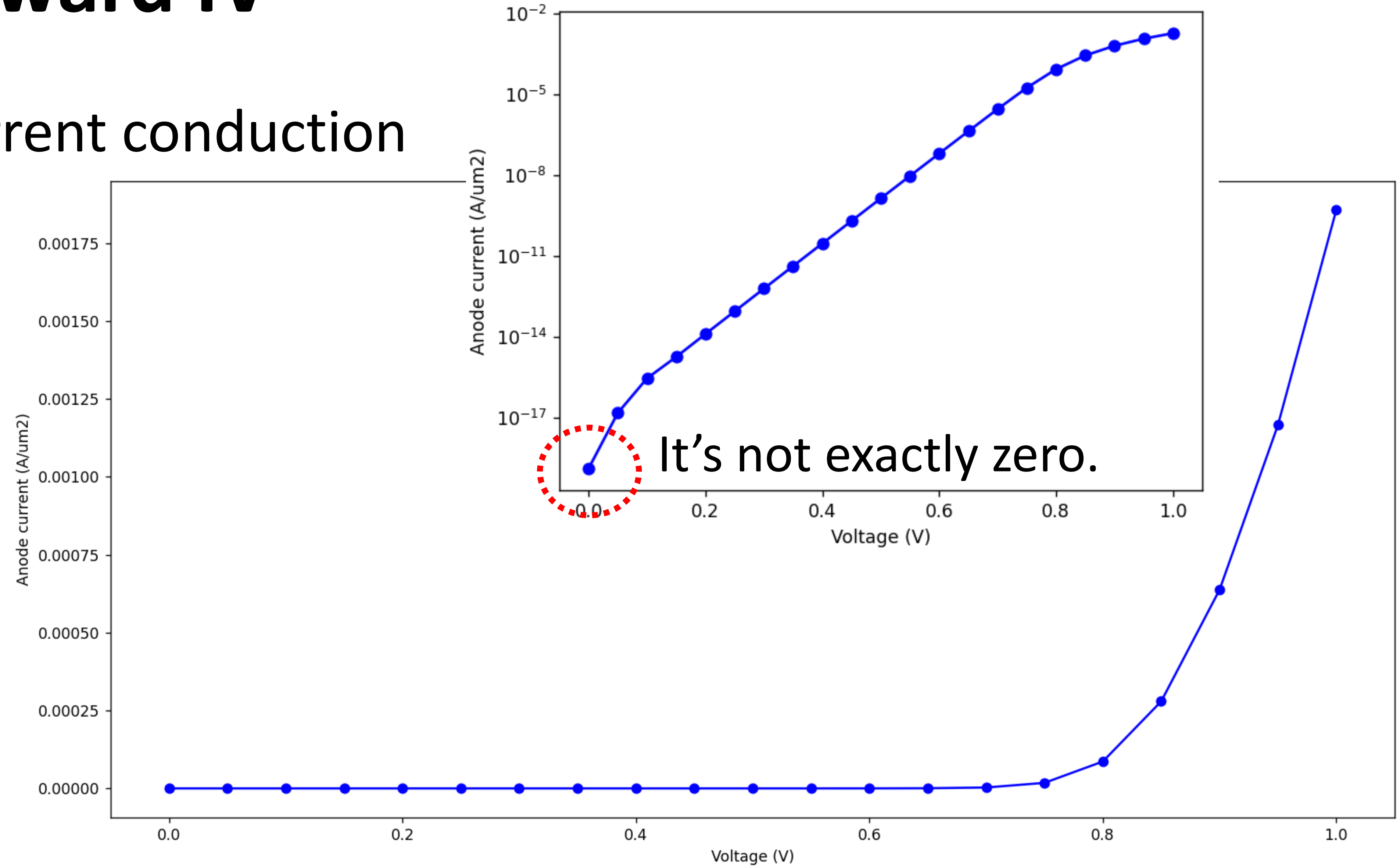
- In a 1D structure, it is very simple.
  - Sum of current densities at the edge connected to the terminal

$$I_{anode} = -(J_p + J_n)A$$



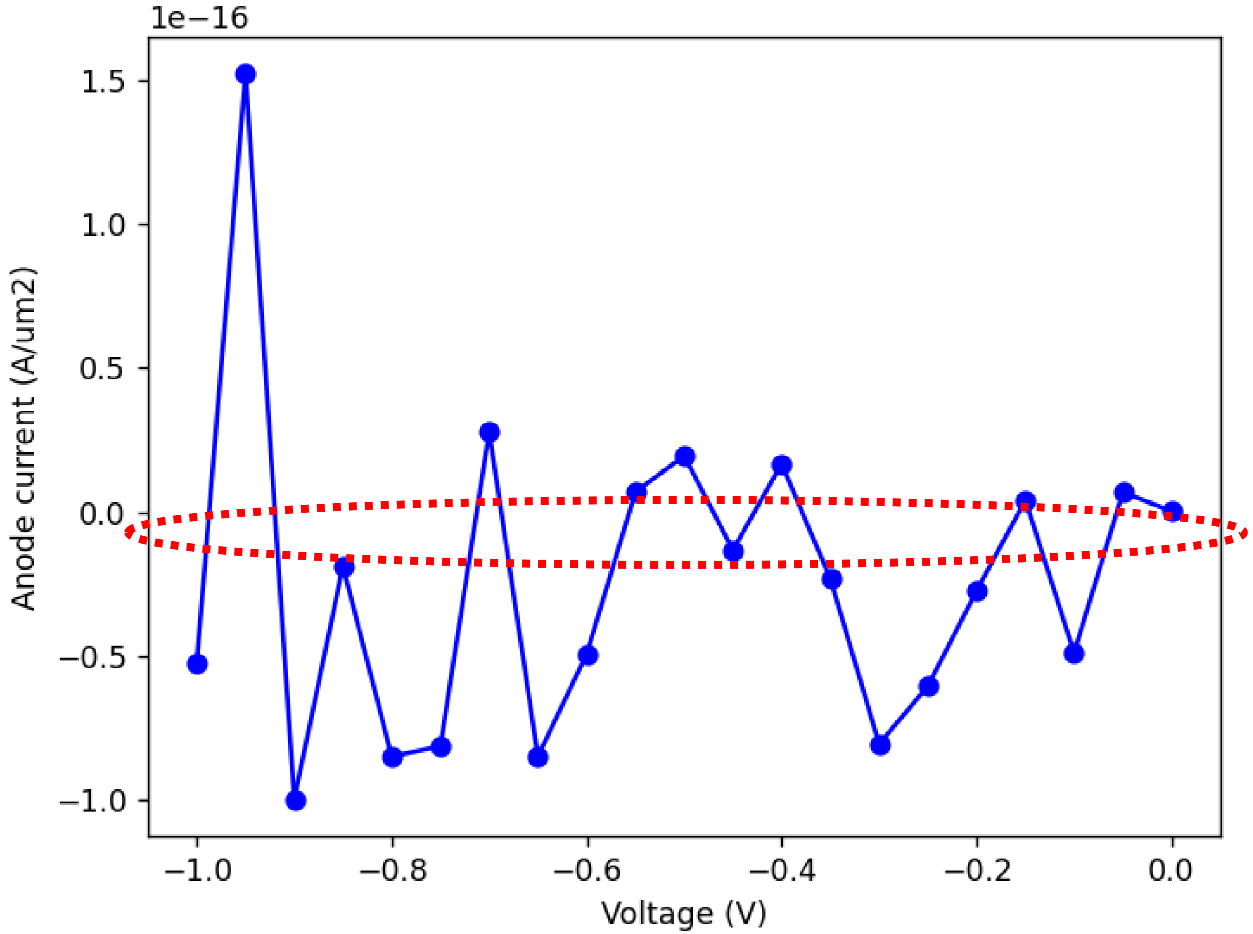
Forward IV

- Current conduction



Reverse IV

- No current conduction



Thank you!