Computational Microelectronics
Lecture 21 Continuity Equation

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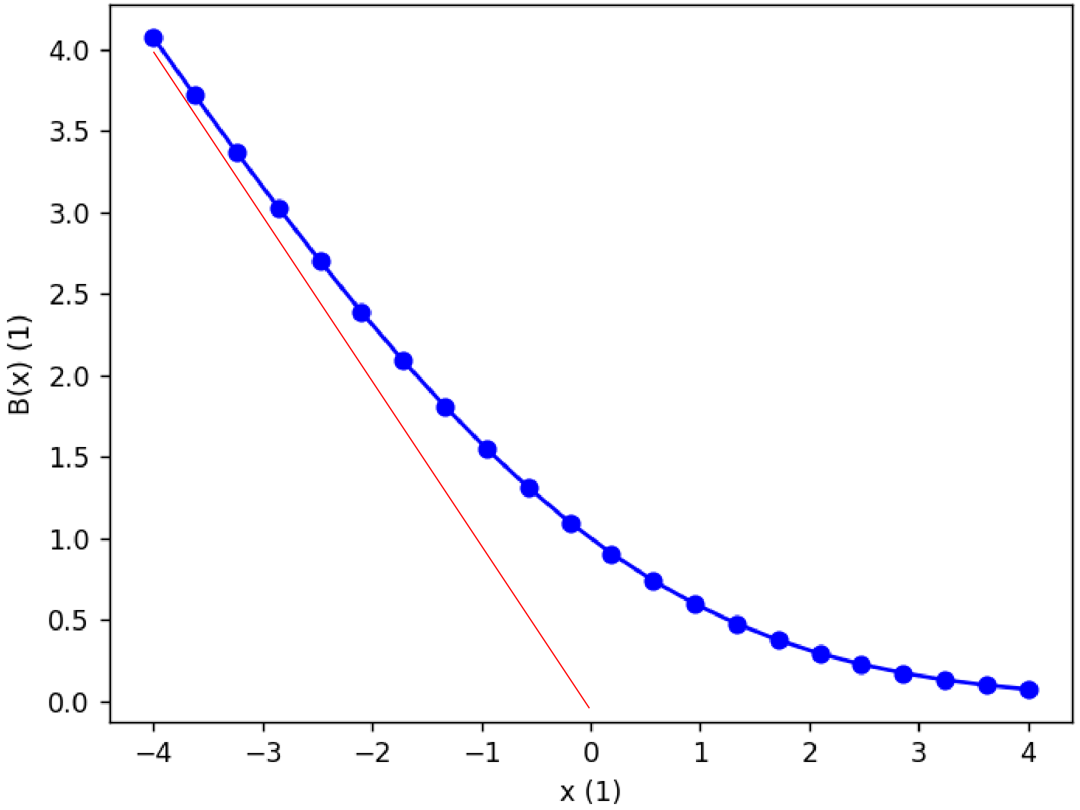
Scharfetter-Gummel Scheme

Bernoulli function, B

- A nonlinear function

$$B(x) = \frac{x}{\exp x - 1}$$

  - 0) $B(x) > 0$ everywhere
  - 1) $B(0) = 1$
  - 2) $B(x) \sim x \exp(-x)$ when $x \to \infty$
  - 3) $B(x) \sim -x$ when $x \to -\infty$
  - 4) Monotonically decreasing
  - 5) $B'(0) = -\frac{1}{2}$
  - Careful implementation is needed.

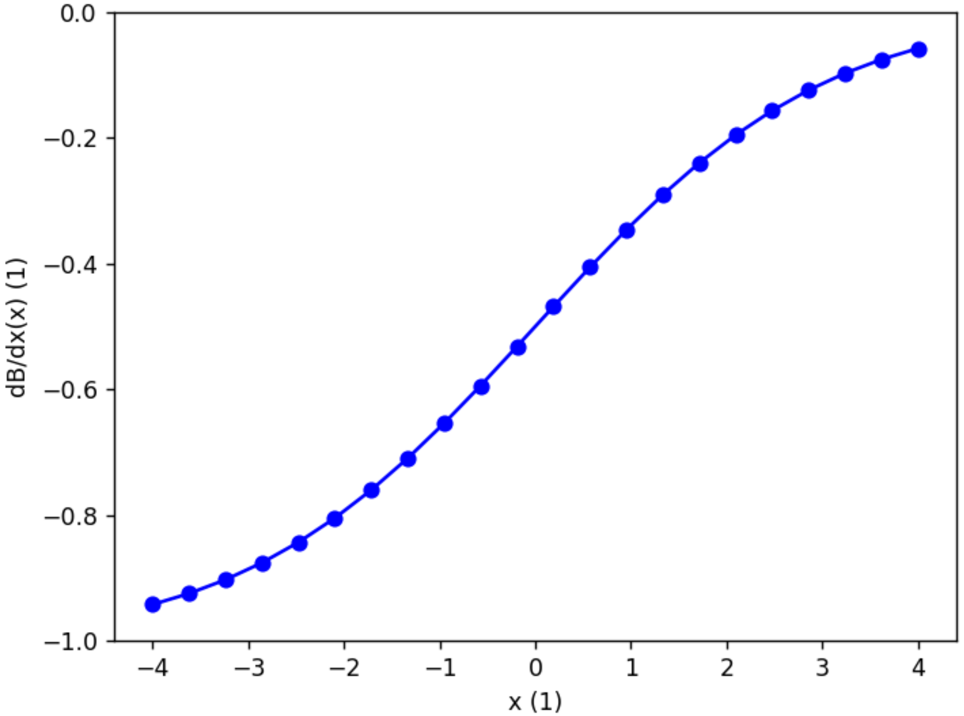


Its derivative, $\boldsymbol{B'}$

- We also need its derivative.

$$B'(x) = \frac{1}{\exp x - 1} - B(x)\frac{\exp x}{\exp x - 1}$$

  - It can be implemented with $B(x)$ and $\frac{1}{\exp x - 1}$.



Jacobian, electron dependence

- Electron current density

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

  - Components of Jacobian matrix are given as

$$\frac{\partial J_n(x_{i+0.5})}{\partial n_{i+1}} = \frac{qD_n}{x_{i+1}-x_i}\left[B\left(\frac{\phi_{i+1}-\phi_i}{V_T}\right)\right] > 0$$

$$\frac{\partial J_n(x_{i+0.5})}{\partial n_i} = \frac{qD_n}{x_{i+1}-x_i}\left[-B\left(-\frac{\phi_{i+1}-\phi_i}{V_T}\right)\right] < 0$$

Jacobian, potential dependence

- Electron current density

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

  – Components of Jacobian matrix are given as

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

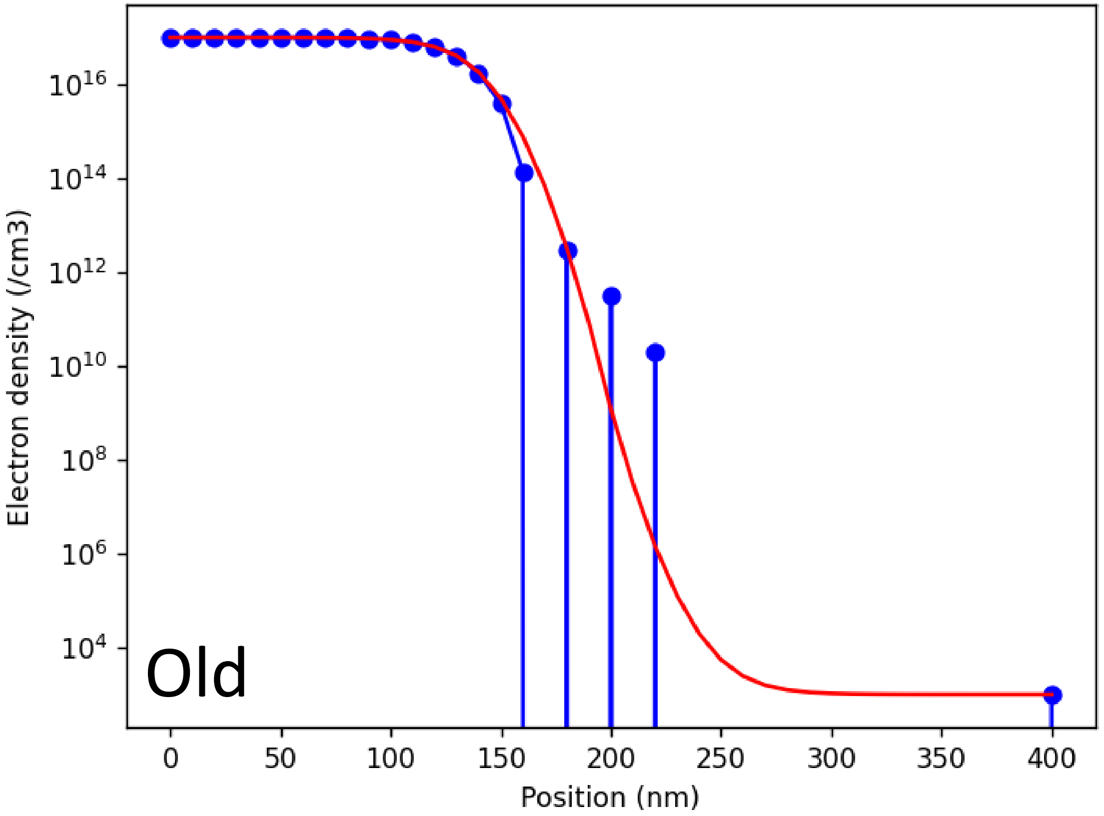
$$\frac{\partial J_n(x_{i+0.5})}{\partial \phi_i} = \frac{qD_n}{x_{i+1} - x_i}\left[-n_{i+1}B'\left(\frac{\phi_{i+1} - \phi_i}{V_T}\right) - n_i B'\left(-\frac{\phi_{i+1} - \phi_i}{V_T}\right)\right]\frac{1}{V_T}$$

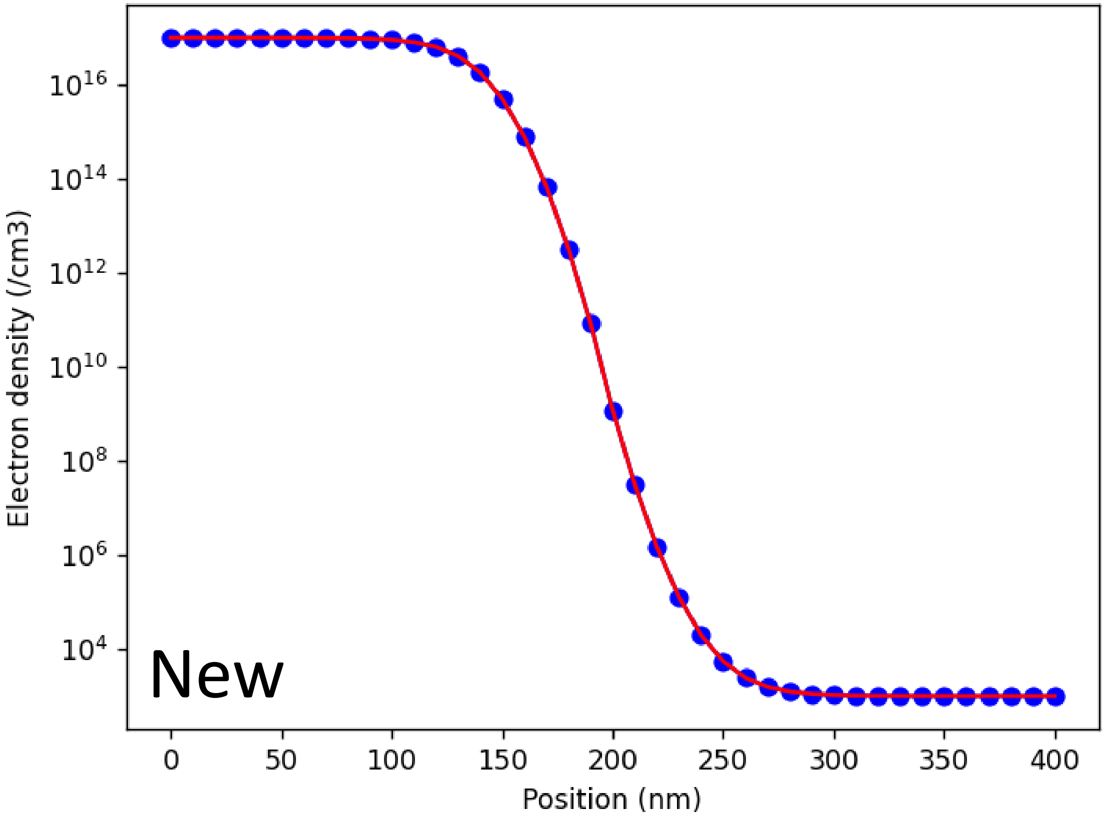
Improved Results

Electron density at equilibrium, again

- 41 mesh points
  - Excellent agreement with the nonlinear Poisson result

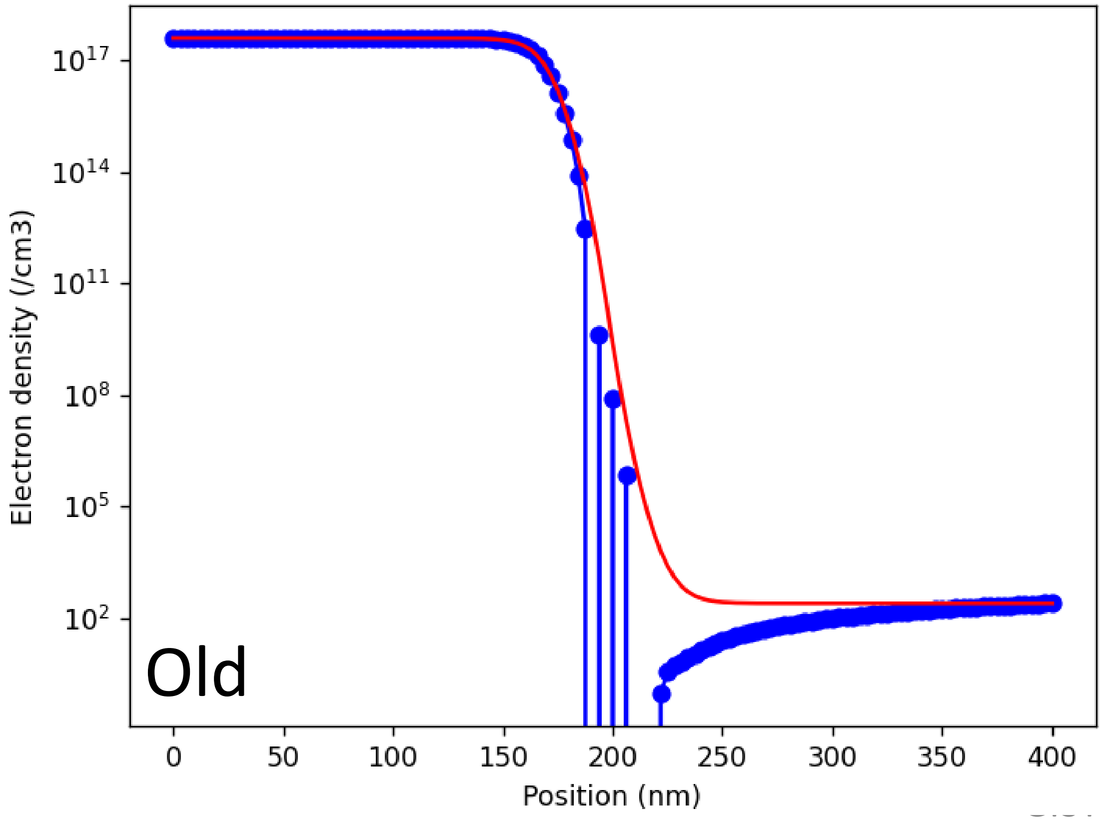
1 2.3322320401031856e-14

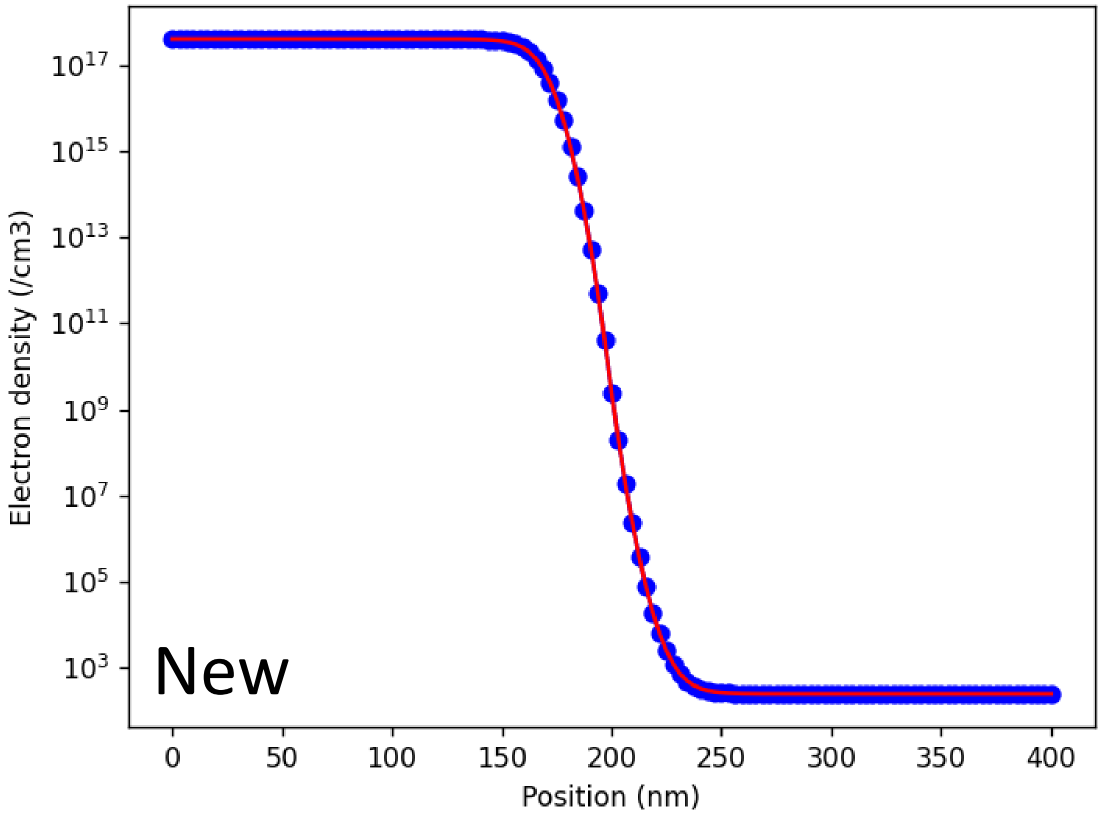




Doping dependence, again

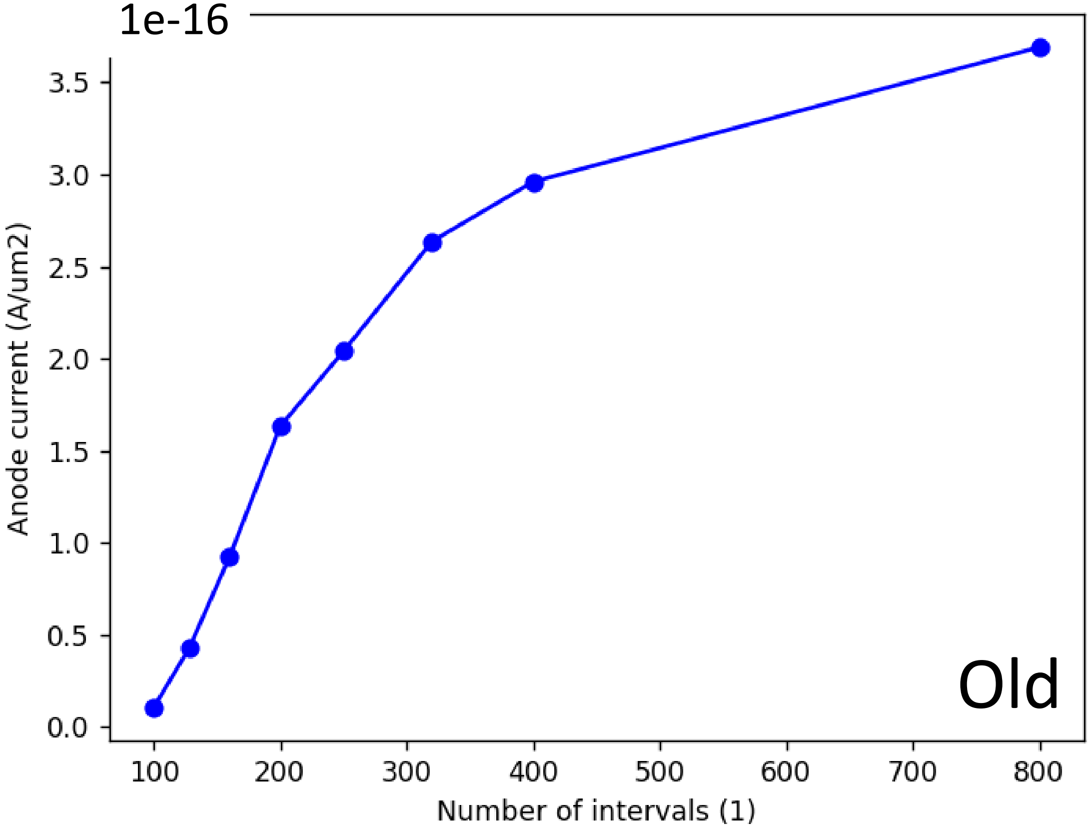
- Spacing of 3.125 nm and $4X10^{17}$ cm^{-3}
  - Excellent agreement with the nonlinear Poisson result

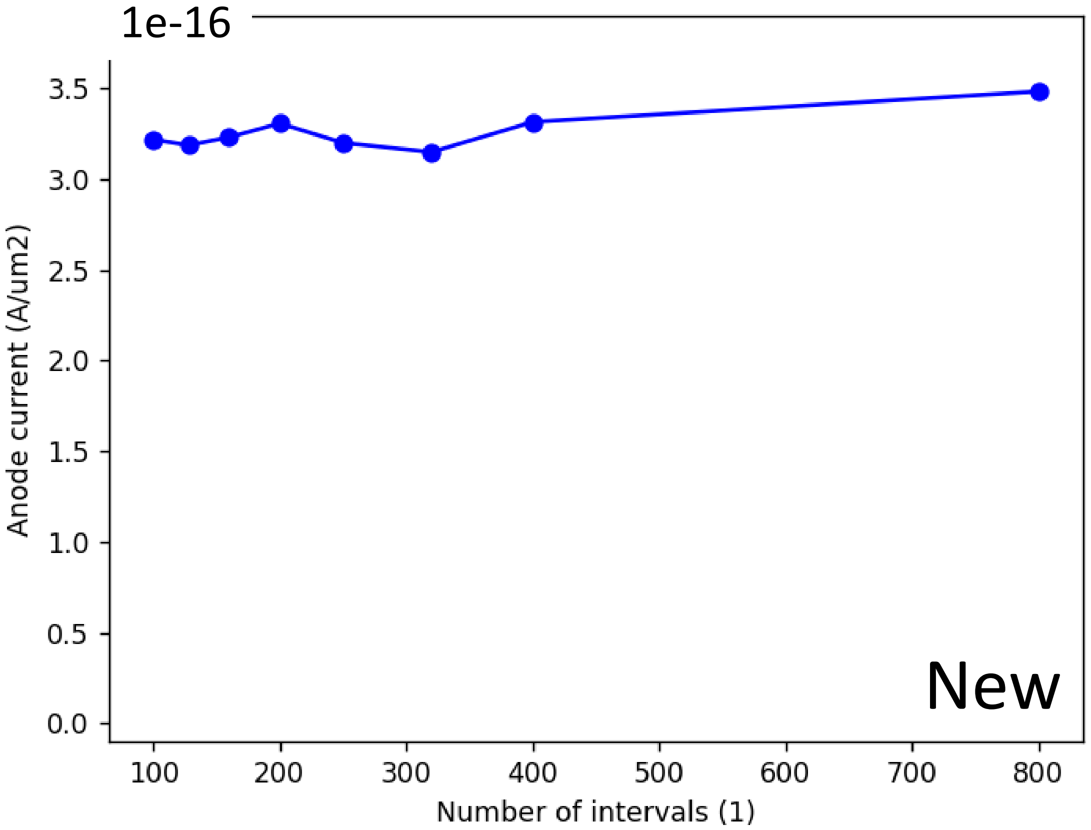




Forward IV, again

- Anode current at V_{anode} = 0.1 V
  - 101, 129, 161, 201, 251, 321, 401, and 801 mesh points
  - Even for 41 mesh points, we have $3.168 X 10^{-16}$ A/um^2.





HW#15

- Due: AM08:00, November 27
- Problem#1
  - In the previous HW#13 and HW#14, three PN junctions were simulated with the nonlinear Poisson equation.
  - In this problem, using the drift-diffusion simulator (Scharfetter-Gummel), simulate the same devices.
- Problem#2
  - Calculate the forward and reverse IV characteristics of the PN junctions, by using the drift-diffusion simulator (Scharfetter-Gummel).

Lecture plan

- We have five remaining lectures. My plan is…
  - L22 (Nov. 22): Transient simulation (1)
  - L23 (Nov. 27): Transient simulation (2)
  - L24 (Nov. 29): Transient simulation (3)
  - L25 (Dec. 4): Small-signal analysis (1)
  - L26 (Dec. 6): Small-signal analysis (2)
  - (Of course, it may change.)
- Term project
  - Due: AM08:00, December 18, 2023 (Submit a recorded video via e-mail.)

Thank you!