Mini Project

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Among the three models, the **Pao-sah** has very less approximation, although the presence of double integral makes them highly computational expensive.

The **Brews** model uses the charge sheet approximation Reducing the expression to one integral however its still not in compact form.

The **Piece-wise** model uses lot of approximation. It’s has a compact form equation making them suitable for adaptation in compact models with some bearable loss in accuracy.

All the 3 modes simulation with expression are shown further.

For NMOS

- **Pao-Sah model**

Pao-Sah Model

Master equation:

$$I_D = \mu_{eff}\frac{W}{L}\int_0^{V_{DS}}[-Q_I(\mathrm{V})]\,dV = q\mu_{eff}\frac{W}{L}\int_0^{V_{DS}}\left[\int_\delta^{\psi_S}\frac{\frac{n_i^2}{N_A}e^{q(\psi-V)/kT}}{\left(-\frac{d\psi}{dx}\right)}d\psi\right]dV$$

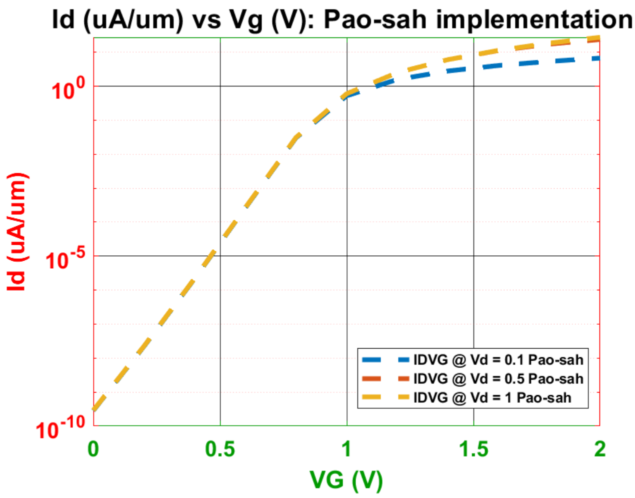
$$\left(-\frac{d\psi}{dx}\right) = \sqrt{\frac{2kTN_A}{\varepsilon_{Si}}}\left[\frac{q\psi}{kT}+\frac{n_i^2}{N_A^2}e^{q(\psi-V)/kT}\right]^{0.5}$$

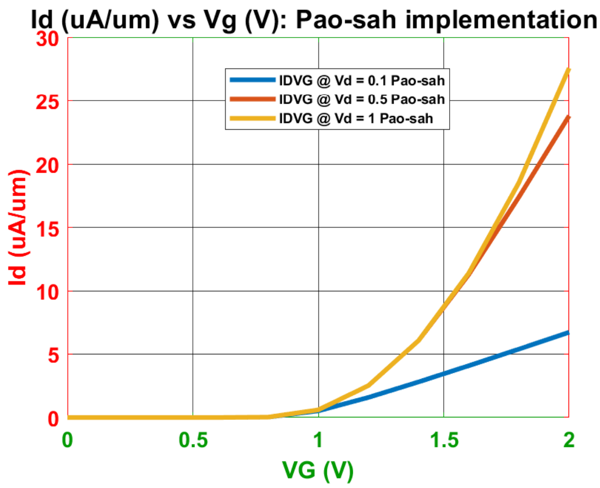
Keeping only relevant terms

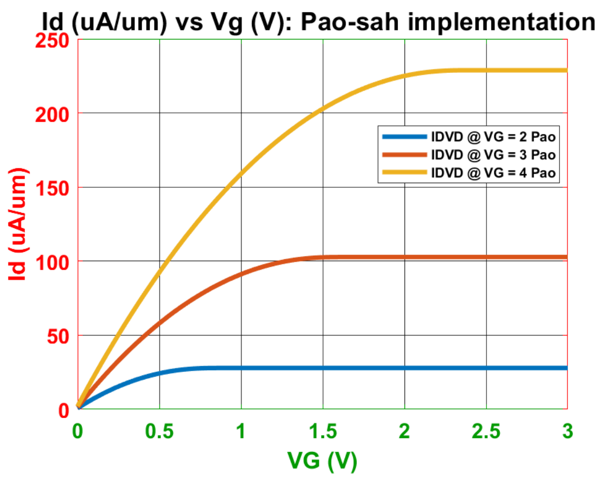
$$V_{GS} = V_{FB} + \psi_S + \frac{\sqrt{2\varepsilon_{Si}kTN_A}}{C_{OX}}\left[\frac{q\psi_S}{kT}+\frac{n_i^2}{N_A^2}e^{q(\psi_S-V)/kT}\right]^{0.5}$$

Find ψ_S at S and D ends for different V_{GS}, V_{DS} using this expression

Numerical solution, valid for all V_{GS}, V_{DS}







- **Brews Model**

Brews Model

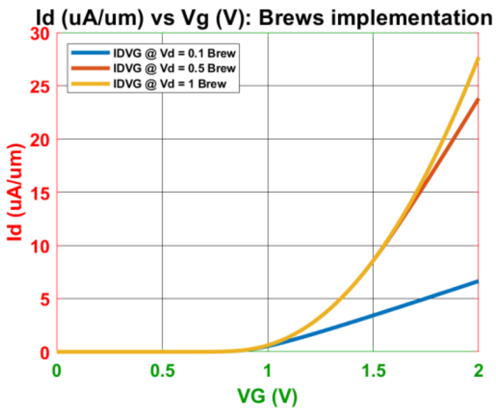
Master equation:

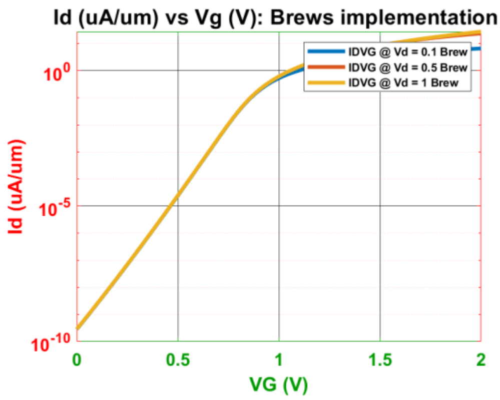
$$I_D = \mu_{eff}\frac{W}{L}\int_{\psi_{SS}}^{\psi_{SD}}[-Q_I(\psi_S)]\frac{dV}{d\psi_S}d\psi_S$$

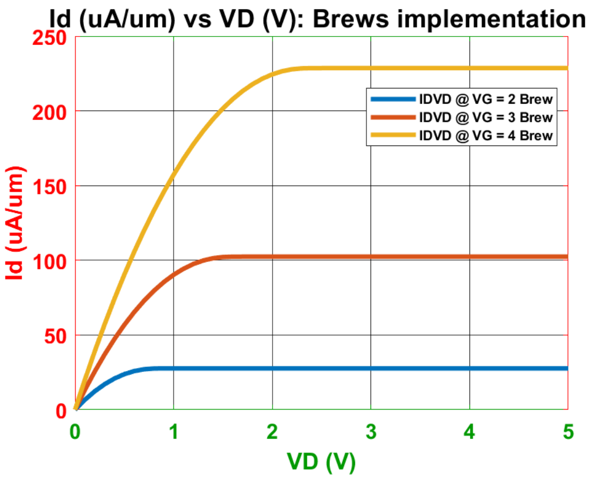
$$= \mu_{eff}\frac{W}{L}\int_{\psi_{SS}}^{\psi_{SD}}\left[C_{OX}(V_{GS}-V_{FB}-\psi_S)-\sqrt{2\varepsilon_{Si}qN_A\psi_S}\right.$$

$$\left.+\frac{2kT}{q}\frac{C_{OX}^2(V_{GS}-V_{FB}-\psi_S)+\varepsilon_{Si}qN_A}{C_{OX}(V_{GS}-V_{FB}-\psi_S)+\sqrt{2\varepsilon_{Si}qN_A\psi_S}}\right]d\psi_S$$

Only a single integral needs to be evaluated (numerically), however, the model is valid for below and above threshold







- **Piece-Wise**

Drain Current Calculation: Linear Region

Drain current above threshold (V_{GS}>V_T), for small V_{DS} values

$$I_D(V_{GS}, V_{DS}) = \mu_{eff}\, C_{OX} \frac{W}{L}\left[\left(V_{GS} - V_T - \frac{mV_{DS}}{2}\right) V_{DS}\right]$$

$$V_T = V_{FB} + 2\phi_B + \frac{\sqrt{4q\varepsilon_{Si} N_A \phi_B}}{C_{OX}}$$

$$m = 1 + \frac{C_D}{C_{OX}}, C_{OX} = \frac{\varepsilon_{OX}}{T_{OX}}, C_D = \frac{\varepsilon_{Si}}{W_D}, W_D = \sqrt{\frac{4\varepsilon_{Si}\phi_B}{qN_A}}$$

Piece-wise expression valid till the onset of pinch-off induced saturation

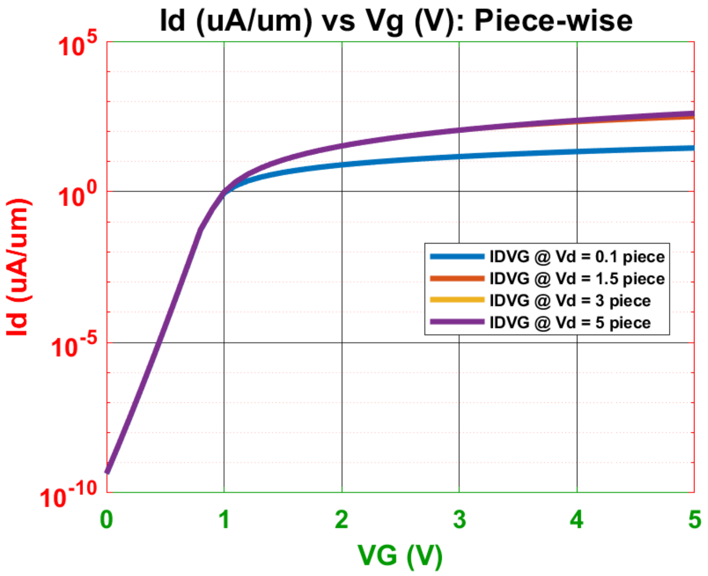
Approximate closed form solution: Subthreshold region

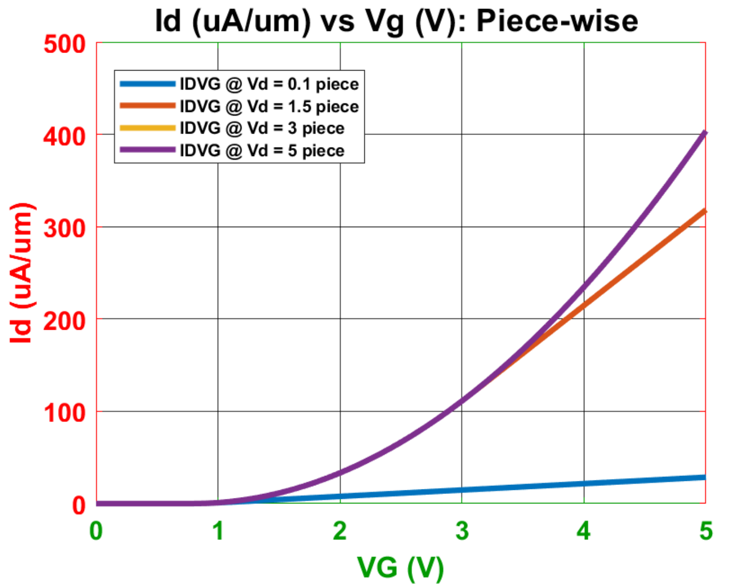
$$I_D(V_{GS}, V_{DS}) = \mu_{eff} \frac{W}{L} C_{OX}(m-1)\left(\frac{kT}{q}\right)^2 e^{q(V_{GS}-V_T)/mkT}\left[1 - e^{-qV_{DS}/kT}\right]$$

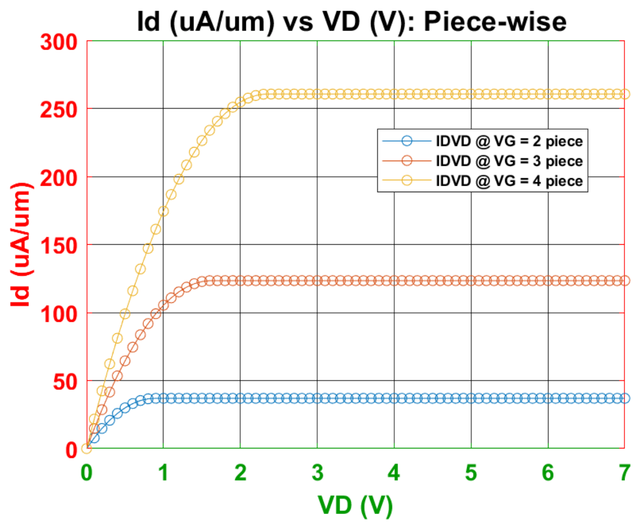
Saturation region:

$$I_{DSAT}(V_{GS}) = \mu_{eff} C_{OX} \frac{W}{L} \frac{(V_{GS} - V_T)^2}{2m}$$

- Piece-wise equations plots

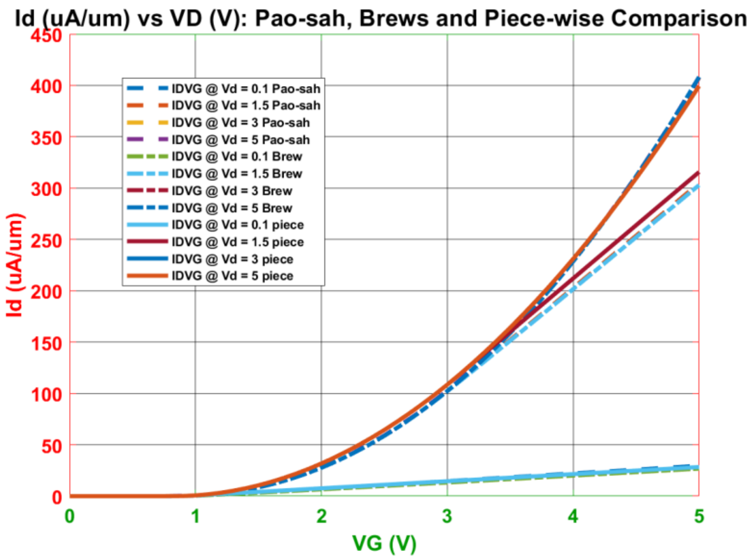


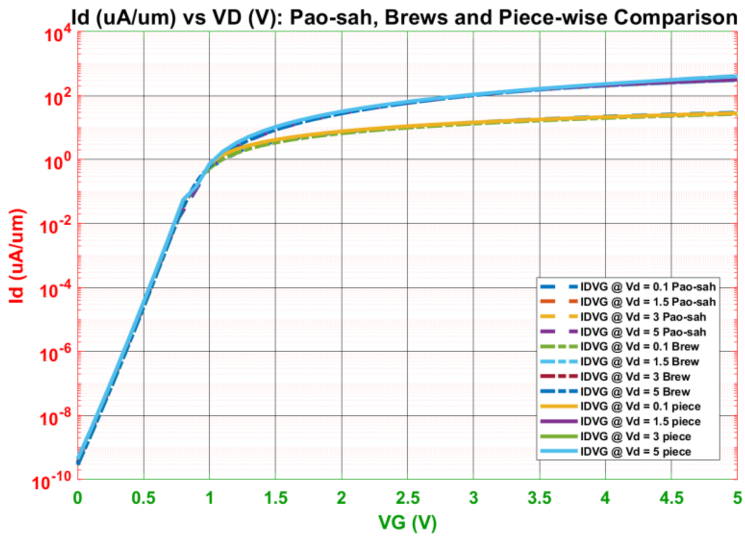



Id (uA/um) vs VD (V): Piece-wise
Id (uA/um)
VD (V)
IDVD @ VG = 2 piece
IDVD @ VG = 3 piece
IDVD @ VG = 4 piece
0
50
100
150
200
250
300
0
1
2
3
4
5
6
7

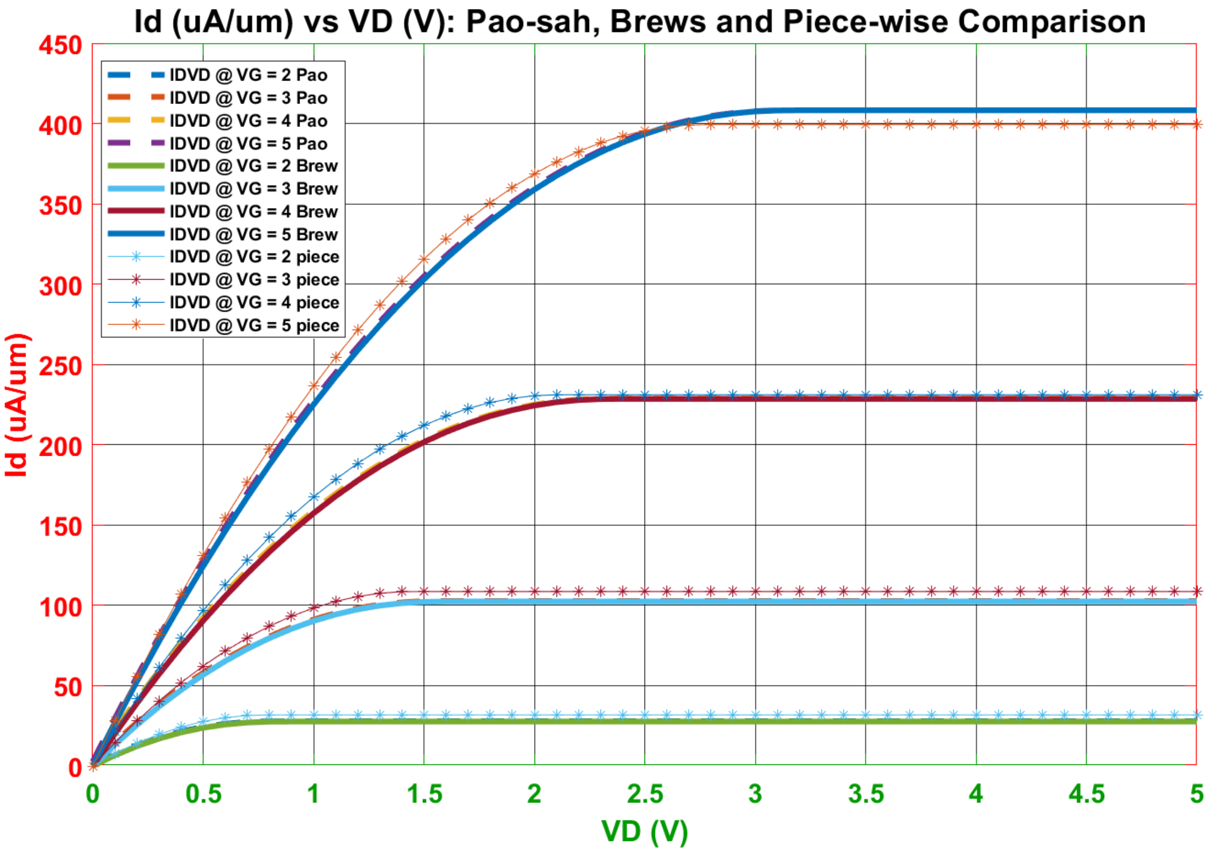
- **Comparison plot**

a. IDVG Comparison





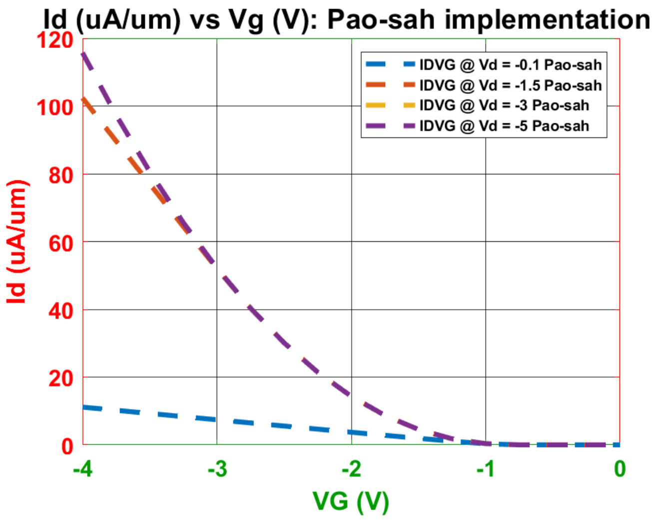
b. IDVD Comparison

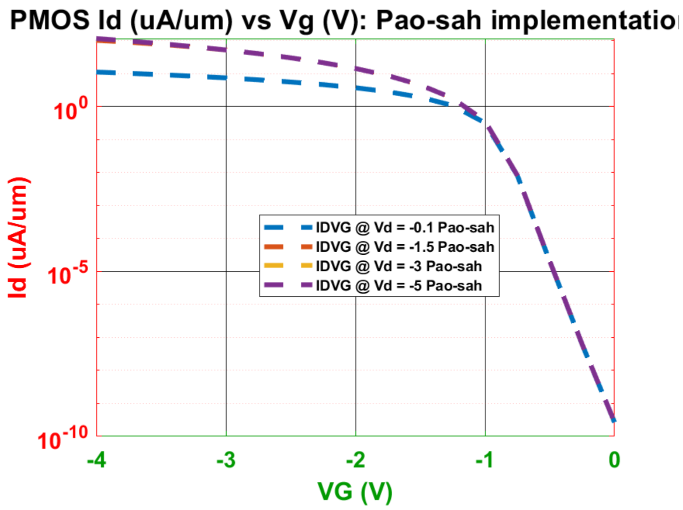


PMOS

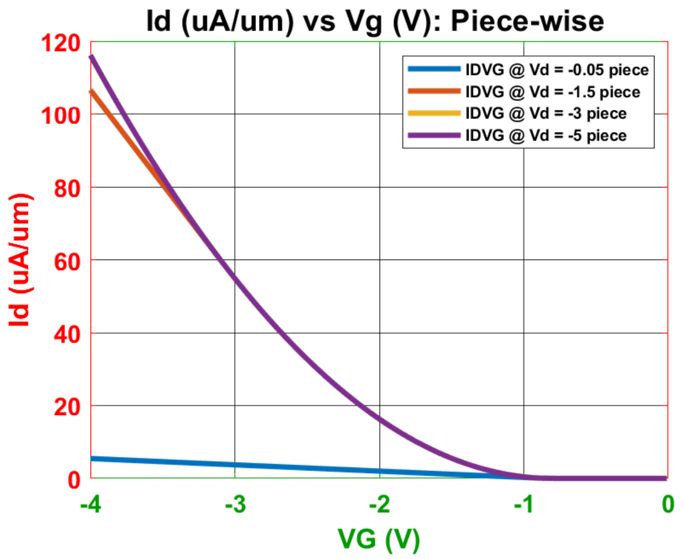
a. IDVG

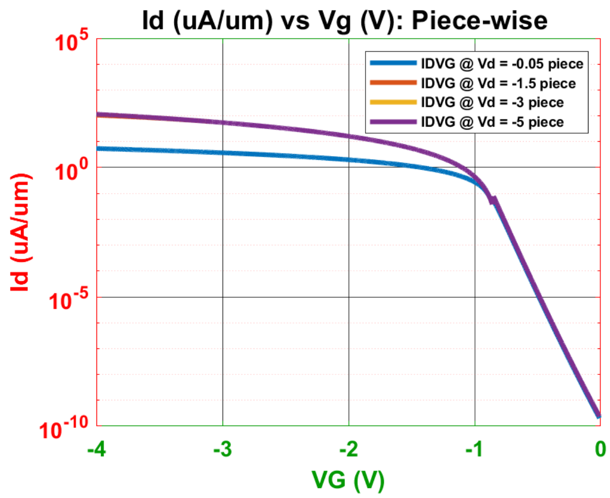
i. Pao-sha



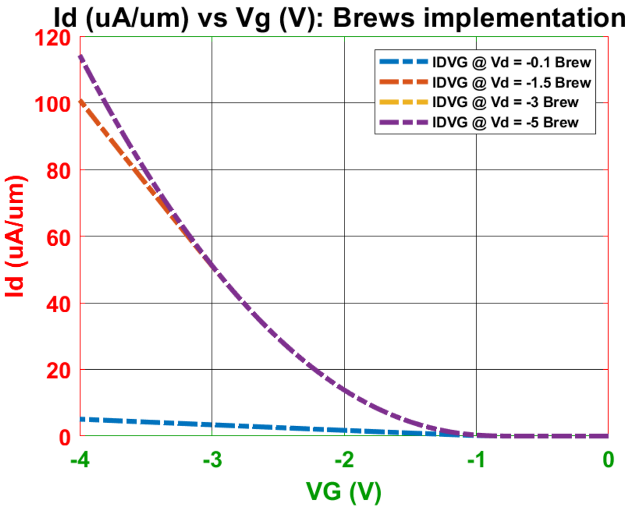


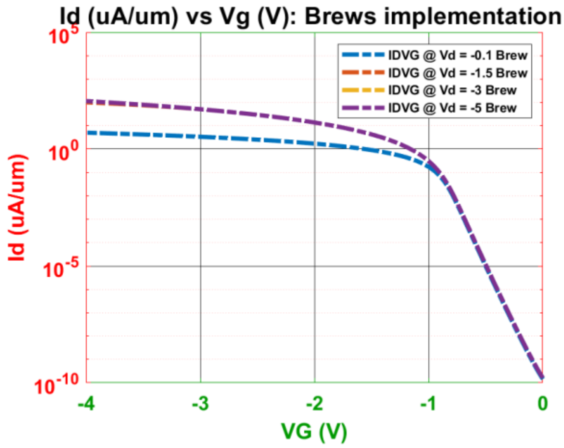
j. Piece-wise



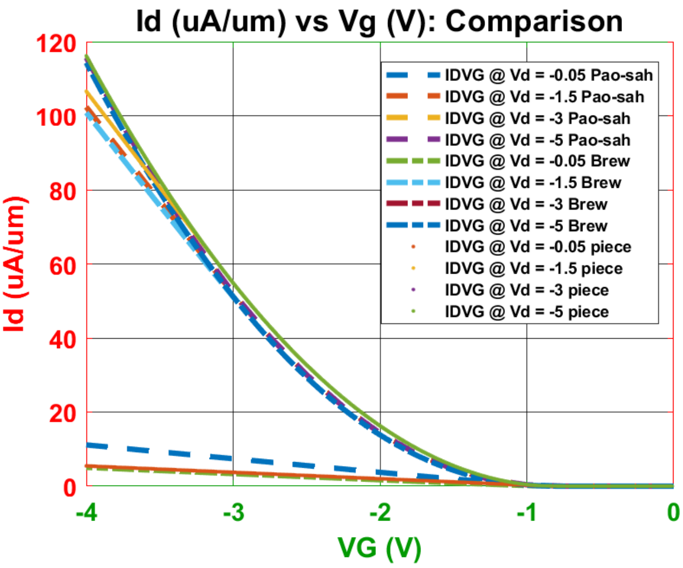


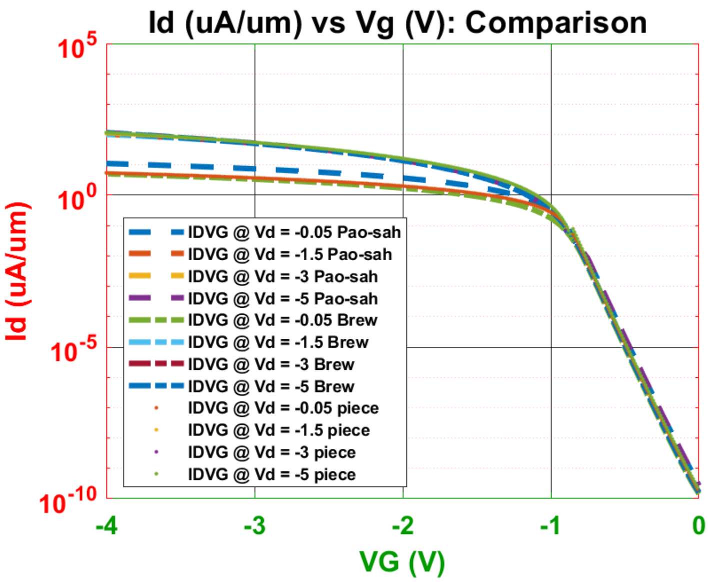
k. Brews



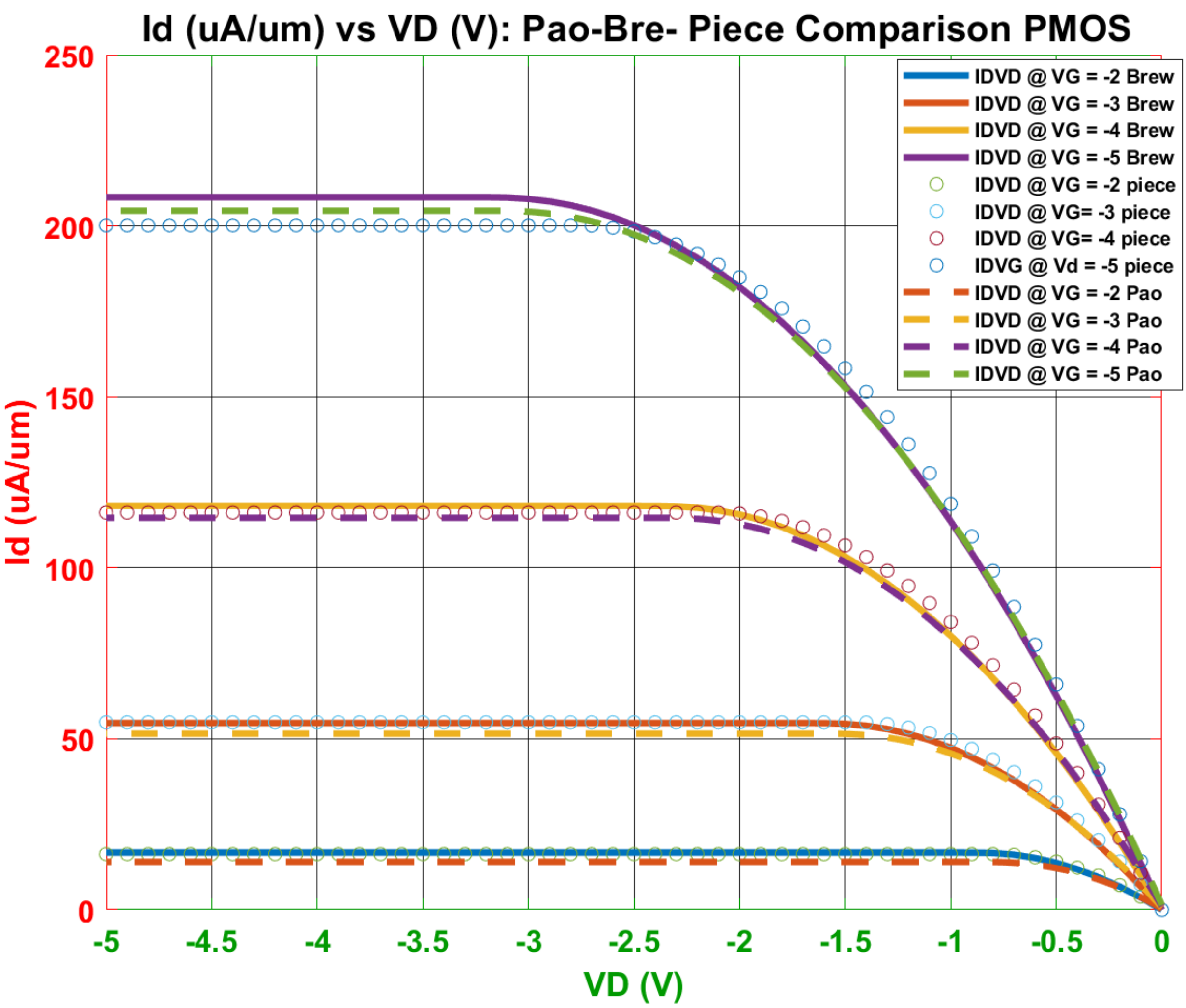


A. IDVG Comparison plots: PMOS





B. IDVD comparison plot: PMOS



All the three models show well consistency and current within the acceptable error bar.

Slide's courtesy: Prof. Souvik