PSP 101.0

PSP Group

March 2006

PENNSTATE

1855

PHILIPS

Outline

- Objectives
- Changes in Local Model
- Gate Current
- Extended Scaling
- Parameter Names
- Conclusions

Objectives

- Address the issues raised by CMC members during model evaluation process
- Prepare for PSP standardization process

This release includes all modifications which will lead to non-backward compatibility. Further additions (fingers, well-proximity, etc.) will be added in a backwards-compatible manner in subsequent releases

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- **Changes in Local Model**
- Gate Current
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Releases and Levels

	Date	Level Implementation	JUNCAP2 Version
1st release	Apr. – 05	100.0	200.0
2nd release	Aug. – 05	100.1	200.1
3rd release	Mar. – 06	101.0	200.1

PSP 101.0 will be made available March 15th, 2006

Changes in Local Model

- Motivated by reciprocity requirement (STm)
  - Removal of lateral gradient factor
    - More traditional DIBL description
    - N(L,W) model of SCE/RSCE
    - Geometry dependence of bulk potential
  - Removal of inner fringing capacitance
- Motivated by symmetry test/ IM3 modeling (Freescale, Jazz, IBM)
  - Improved CLM description
  - Improved V_{BS} clamping for high forward bias (V_{BS} >1V)

Improved CLM Model (Better Description for Low V_{ds})

$$\frac{\Delta L_1}{L} = \left(\mathbf{ALP} + \frac{\mathbf{ALP\,1}}{q_{im}^{*}} R_1 \right) T_1 + \mathbf{ALP2} \cdot q_{bm} \cdot R_2^2 \cdot T_2$$

$$T_1 = \ln \left(\frac{1 + \frac{V_{DS} - \Delta\psi}{\mathbf{VP}}}{1 + \frac{V_{dse} - \Delta\psi}{\mathbf{VP}}} \right); \qquad T_2 = \ln \left(1 + \frac{V_{dsx} - \Delta\psi}{\mathbf{VP}} \right)$$

- Expressions for T1 and T2 have been changed in PSP 101.0
- Same physical motivation, usage
- Similar numerical values
- Better for IM3 applications (see symmetry tests plots below)

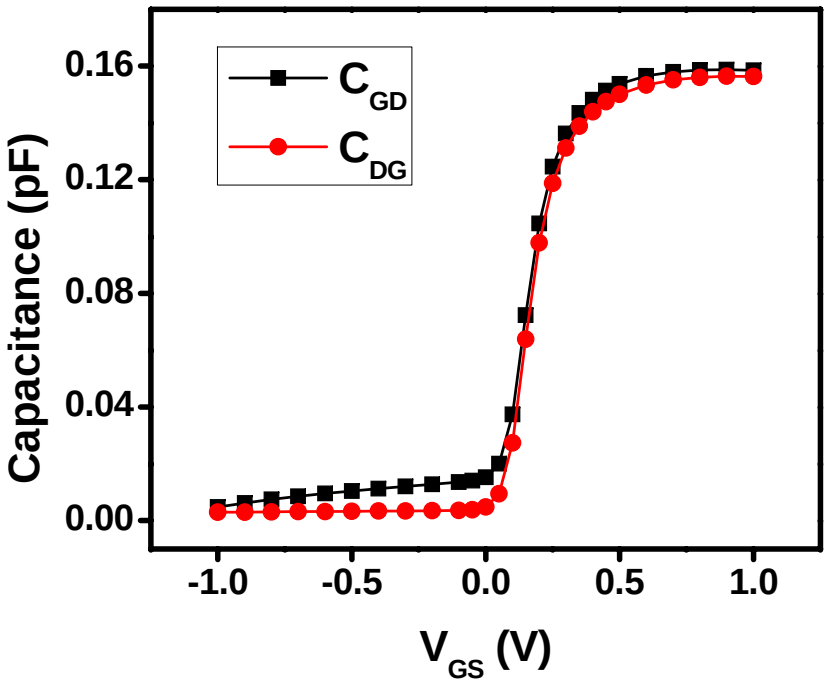
Reciprocity Requirement

- Generally speaking, $C_{ij} \neq C_{ji}$. But for a special case of $V_{DS}=0$, $C_{ij}=C_{ji}$. For example, $C_{GD}=C_{DG}$ and $C_{GB}=C_{BG}$

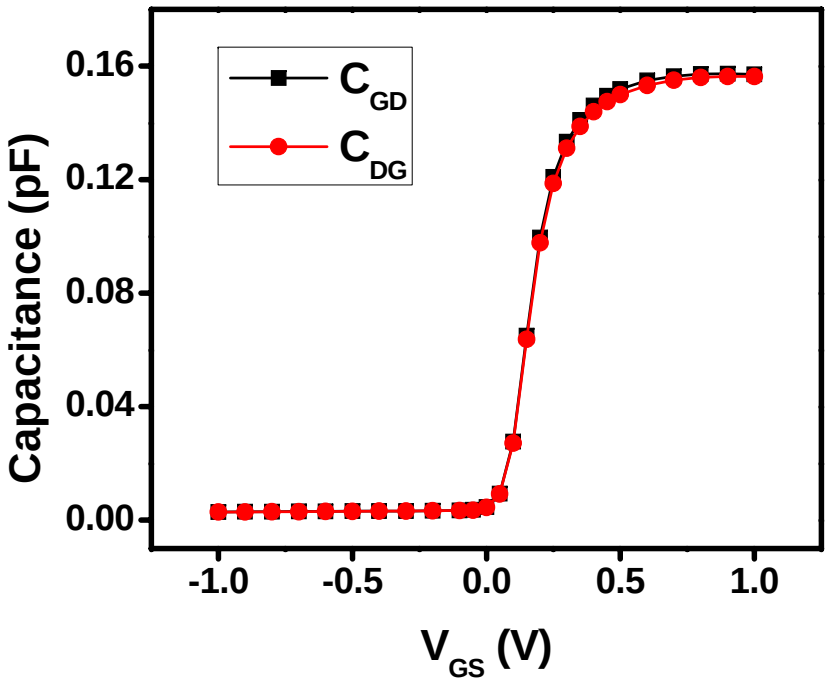
  This requirement is rather subtle (violated in most models) and could not be satisfied with physically motivated but semi-empirical models of bias-dependent lateral gradient factor and inner fringing in PSP 100.1. Satisfied in PSP 101.0 to the extend allowed by the charge-sheet approximation (1% of C_{OX} or better)

- Complete symmetry of PSP implies that for $V_{DS}=0$ $C_{SD}=C_{DS}$ exactly (in all versions)

Reciprocity Test

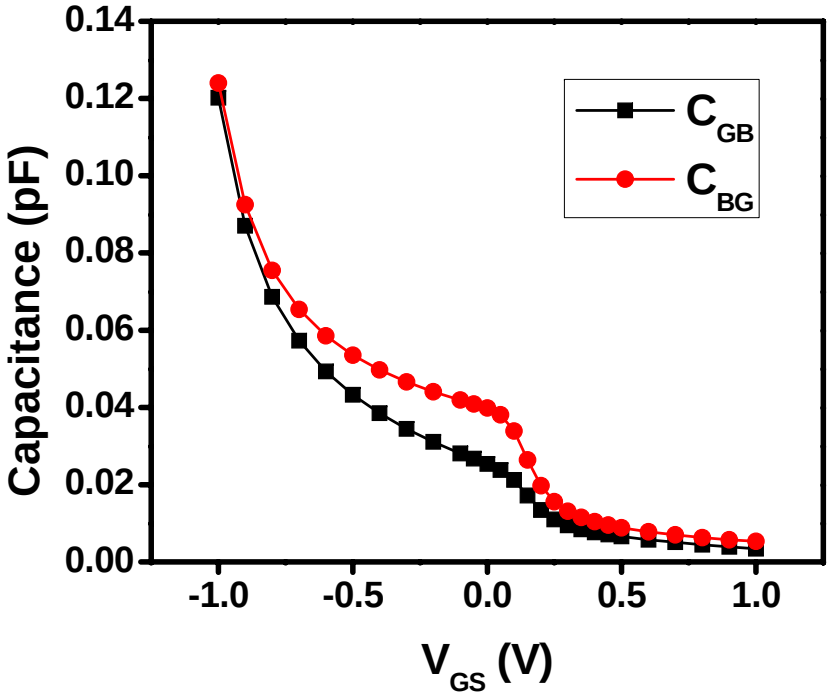


PSP 100.1

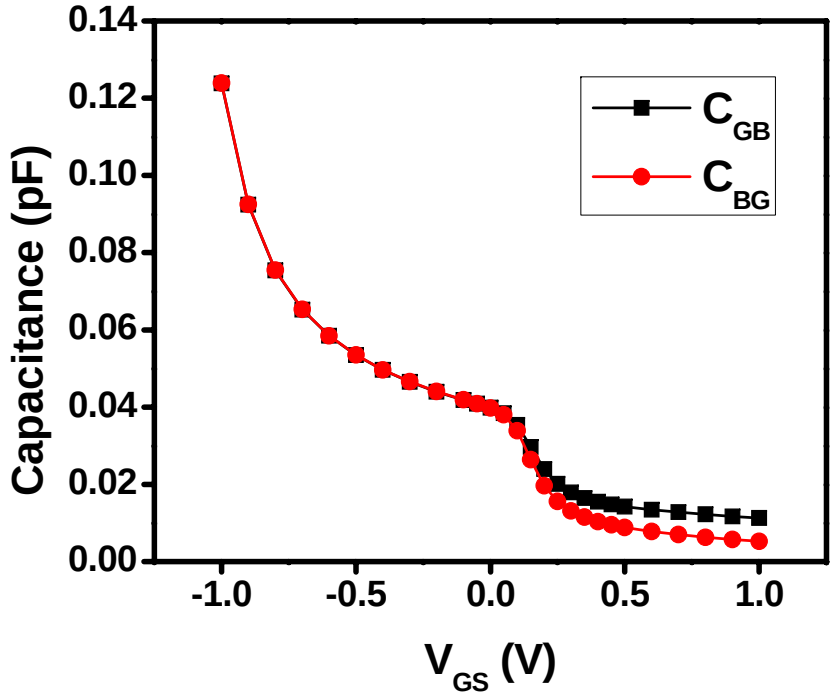


PSP 101.0

Reciprocity Test (cont.)

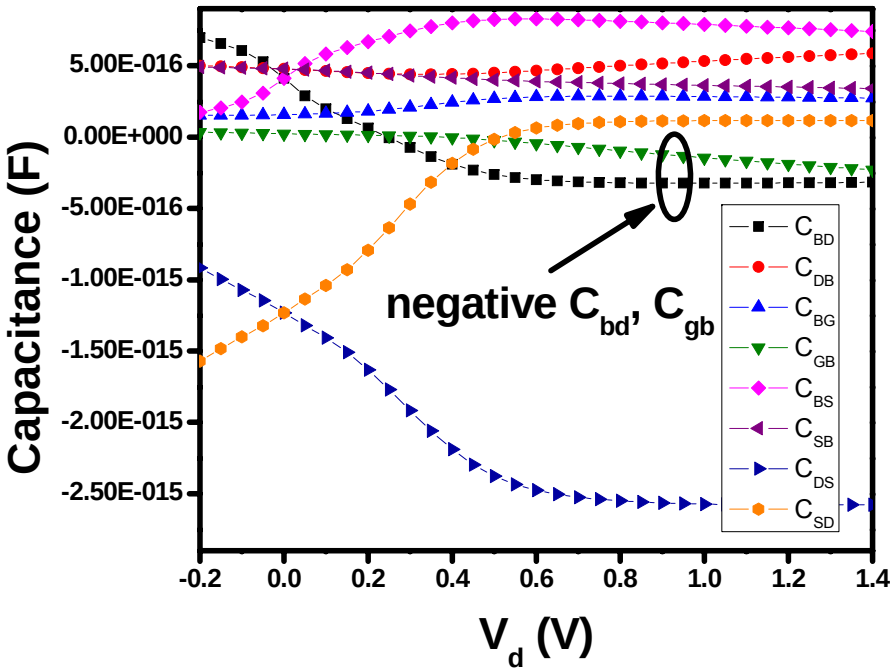


PSP 100.1

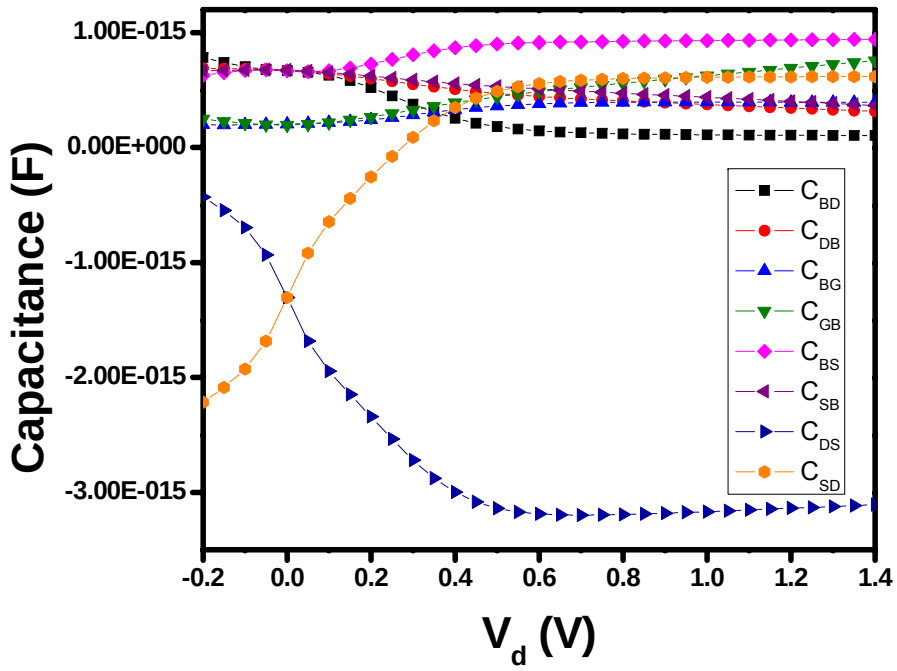


PSP 101.0

Negative Capacitances (Freesacle)



PSP 100.1



PSP 101.0

W/L=10/0.08μ, V_b=-0.1V, V_g=1.2V

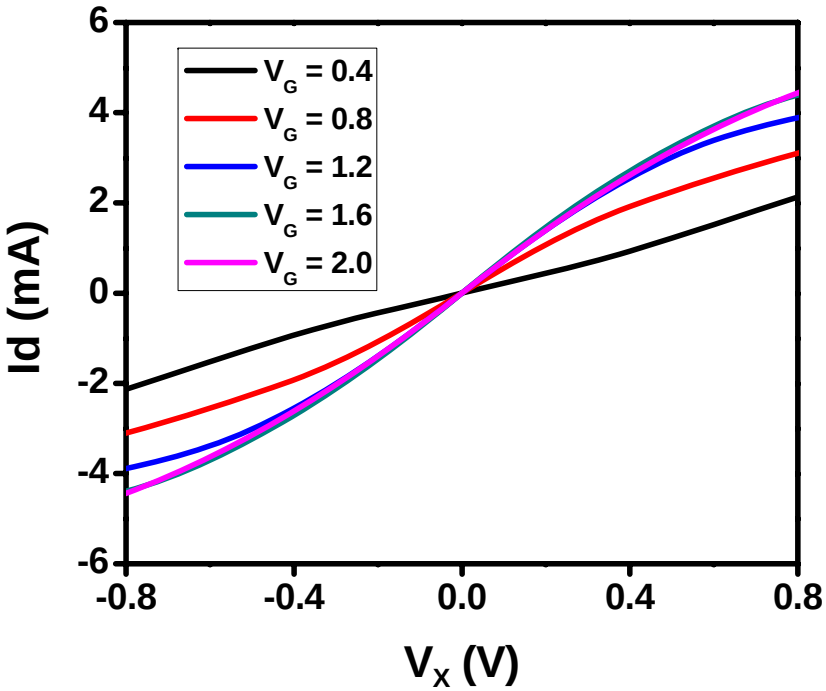
DIBL Model in PSP 101.0

$$\Delta V_G = \mathbf{CF} \cdot V_{dsx} \left(1 + \mathbf{CFB} \cdot V_{sbx}\right)$$

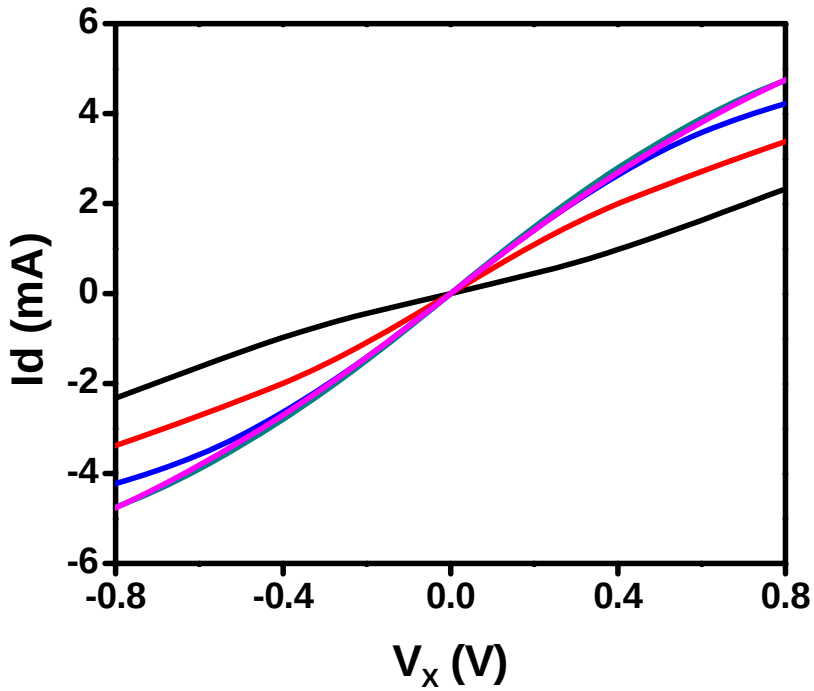
$$\mathbf{CF} = \mathbf{CFL} \left(\frac{L_{EN}}{L_E}\right)^{\mathbf{CFLEXP}} \left(1 + \mathbf{CFW} \frac{W_{EN}}{W_E}\right)$$

$$\mathbf{CFB} = \mathbf{CFBO}$$

Gummel Symmetry Test (GST): Drain Current



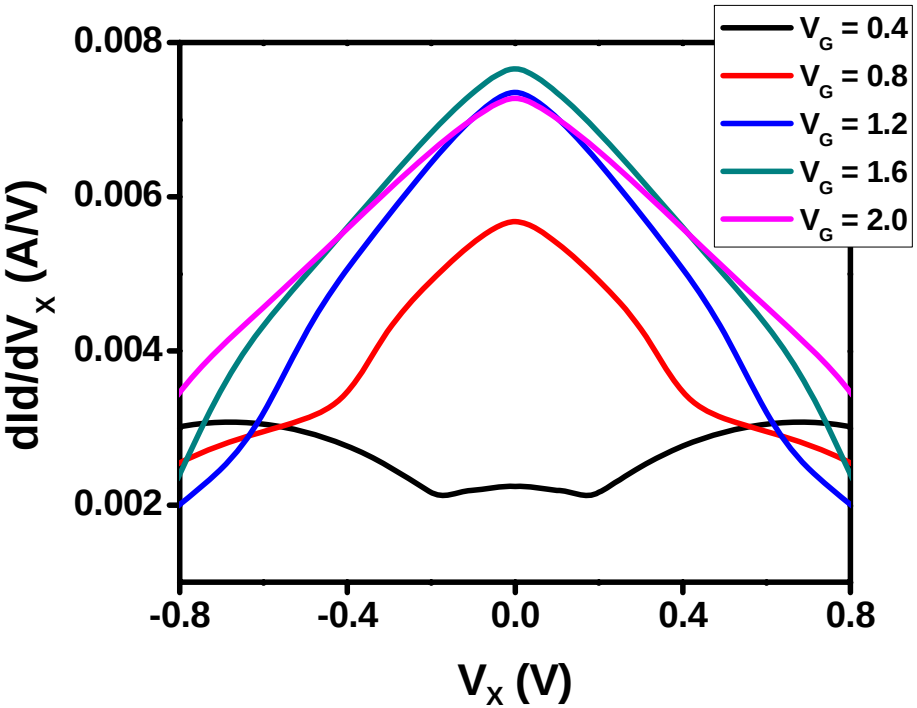
PSP 100.1



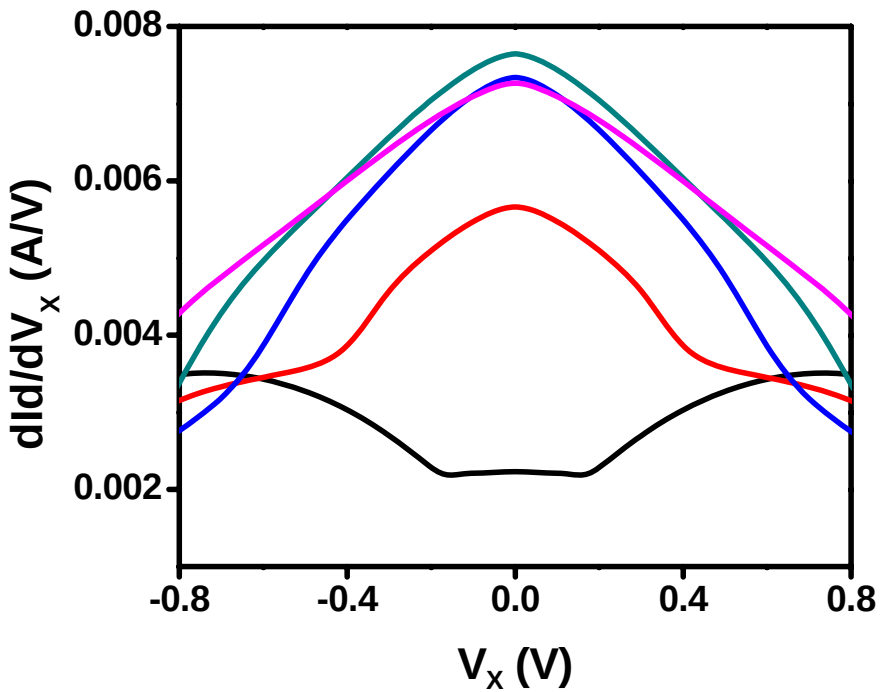
PSP 101.0

W/L = 10/1 (µm) for all GST in this presentation

GST: 1st derivate of I_d

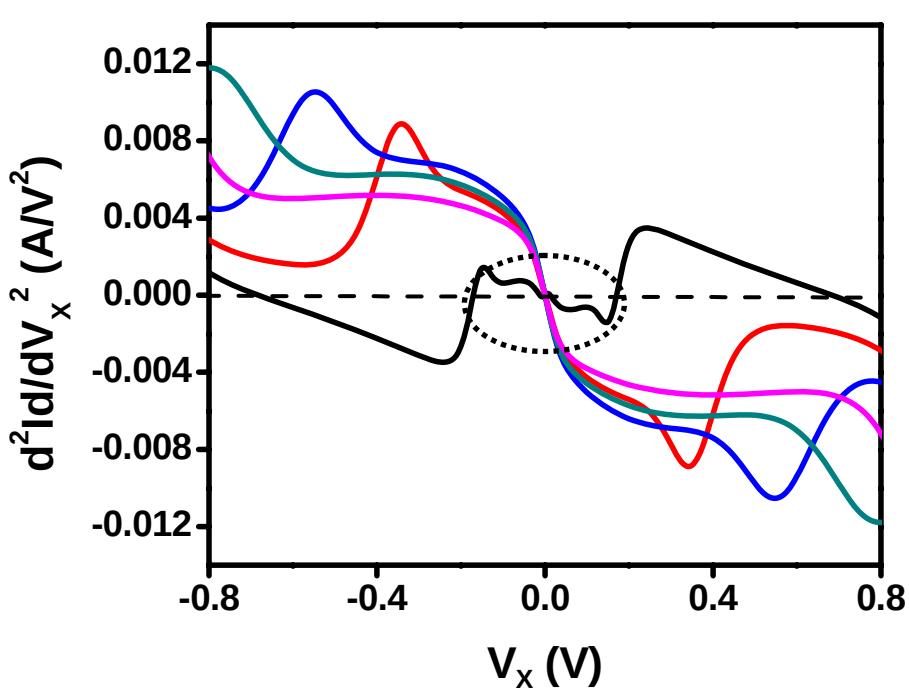


PSP 100.1

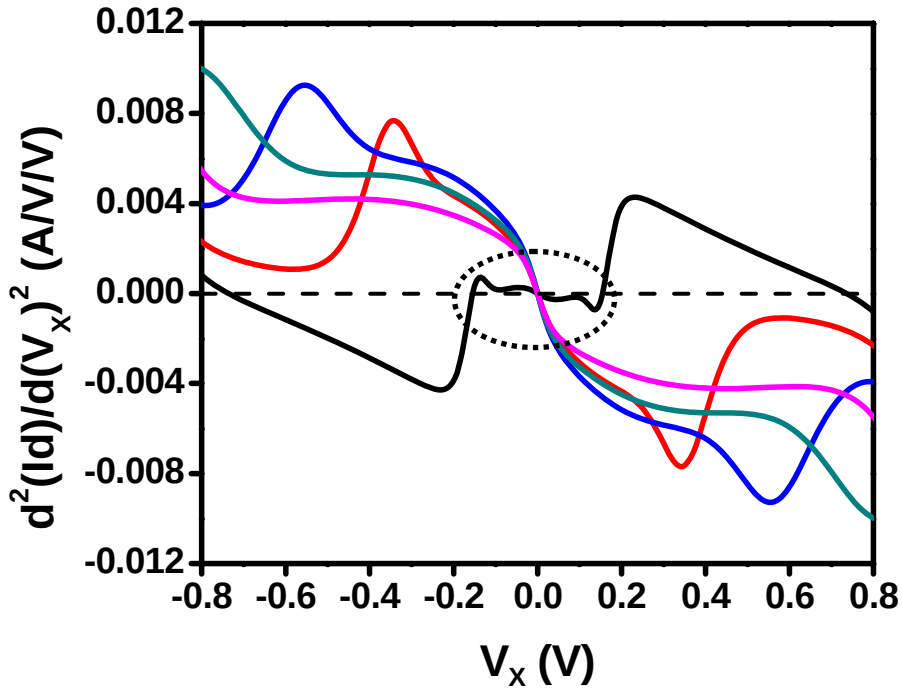


PSP 101.0

GST: 2nd derivative of I_d

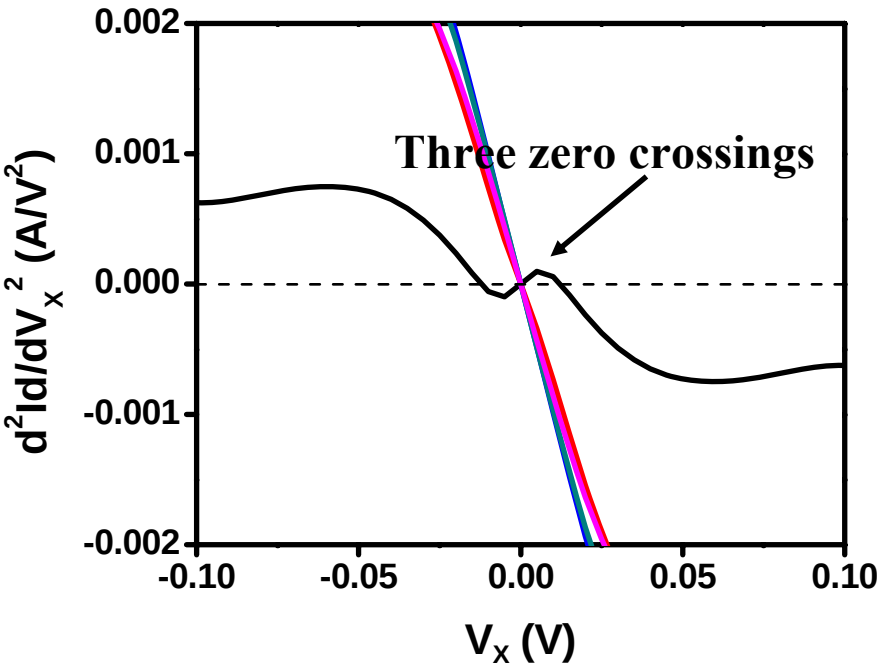


PSP 100.1

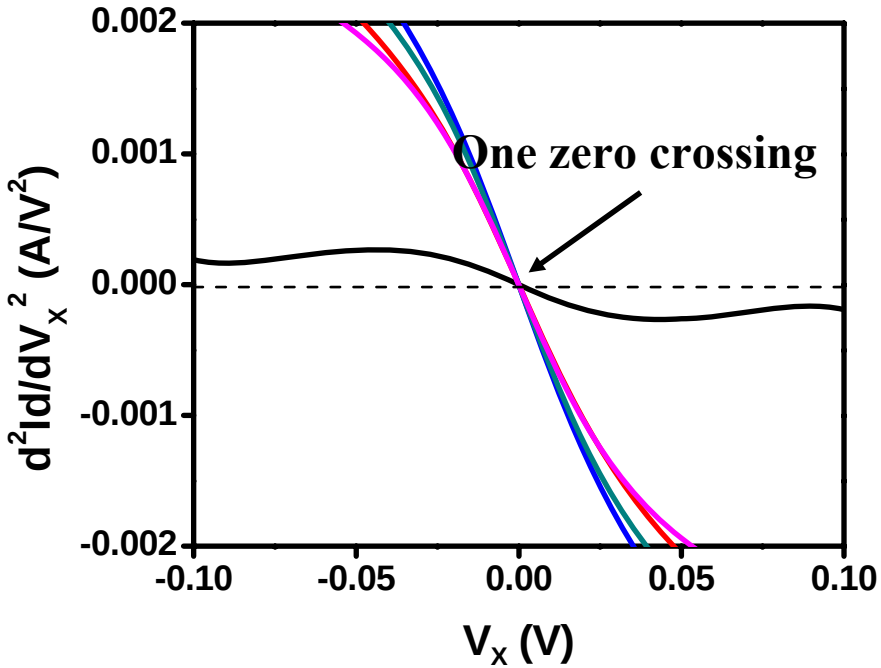


PSP 101.0

GST:
2nd derivative of I_d in detail



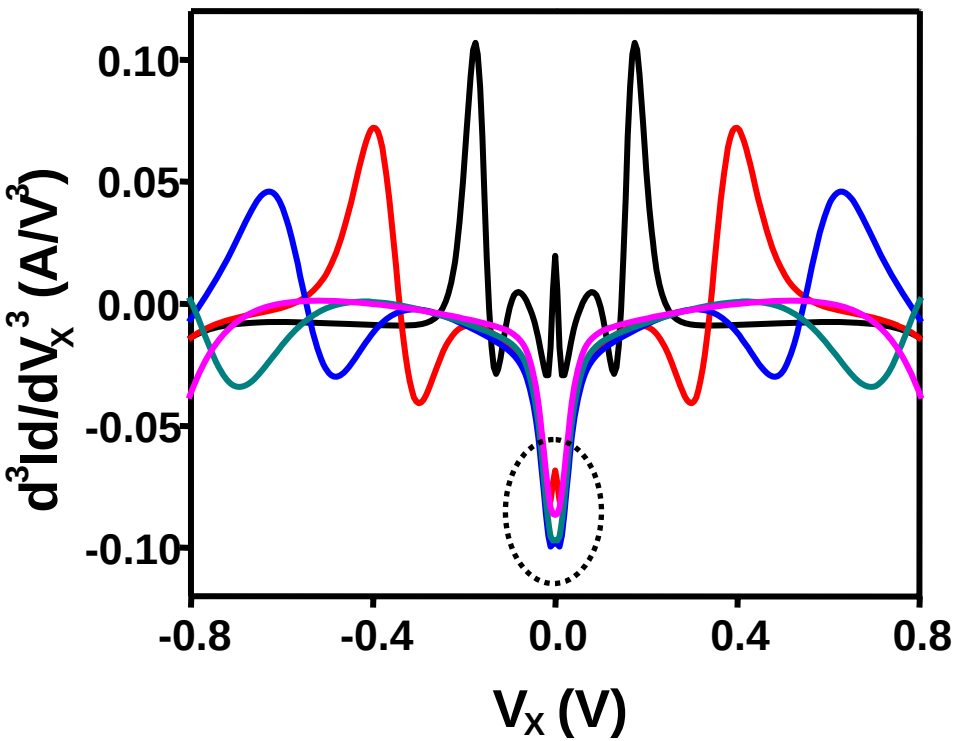
PSP 100.1

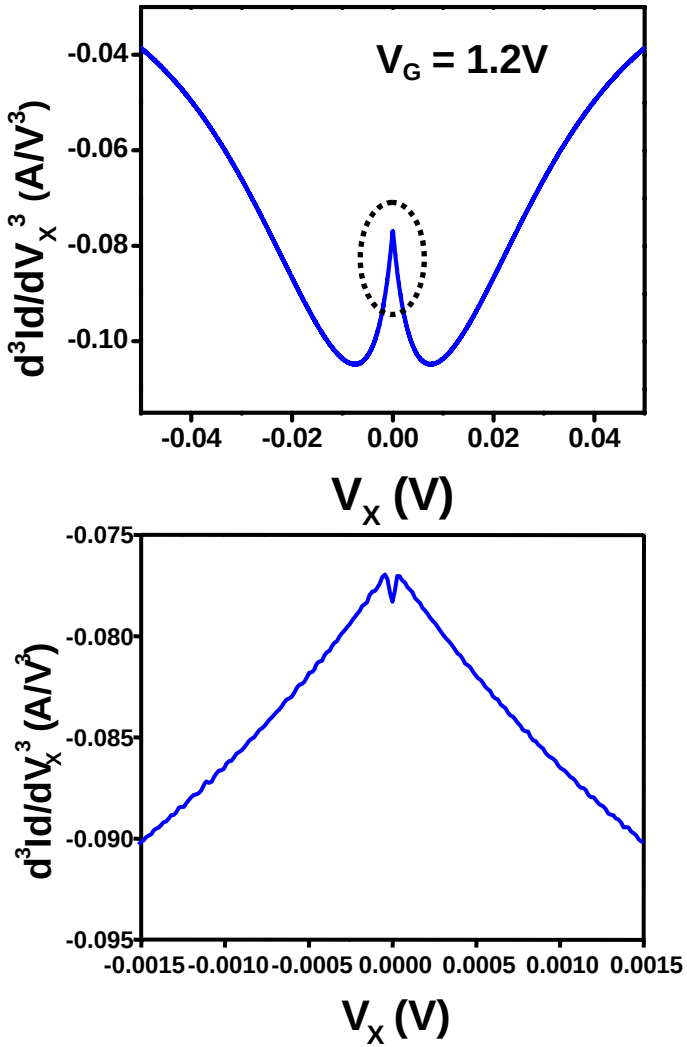


PSP 101.0

GST: 3rd derivative of I_d

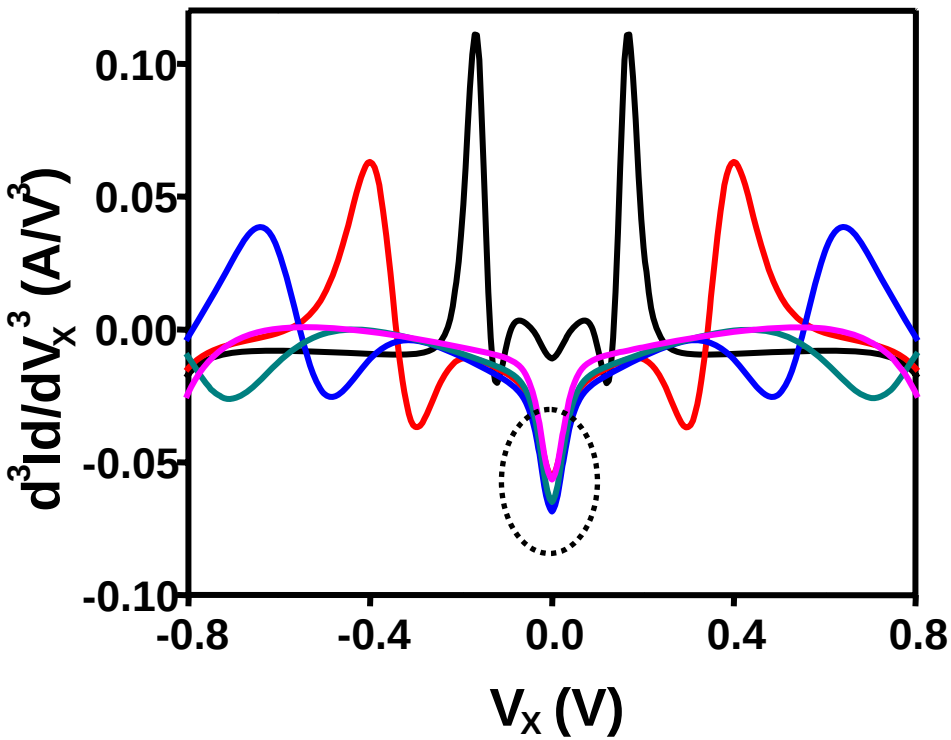
PSP 100.1

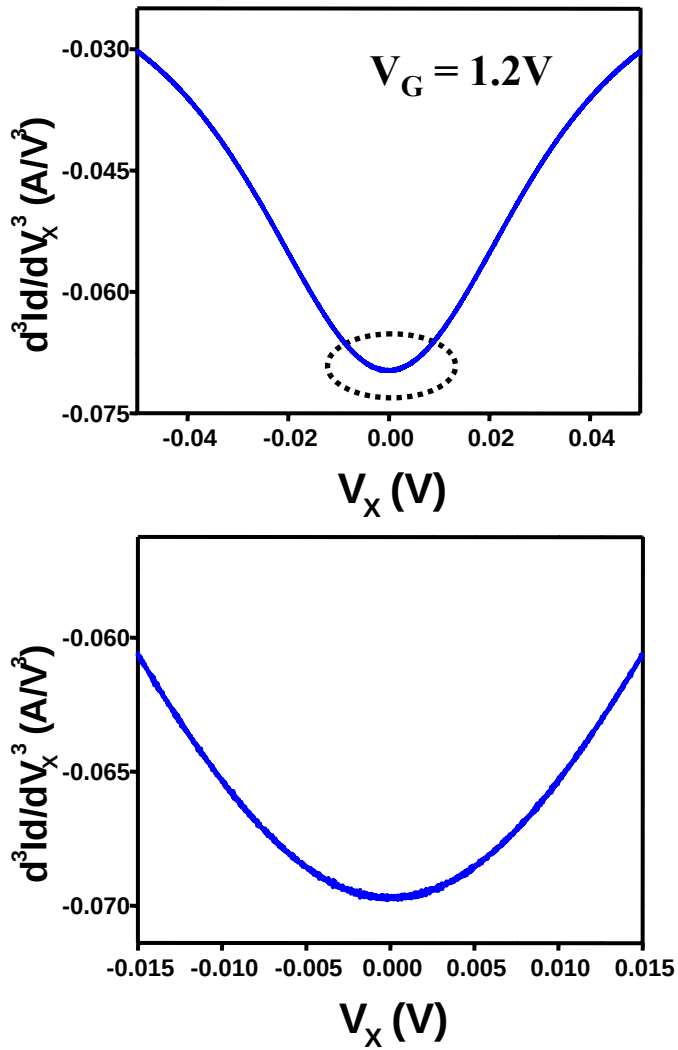




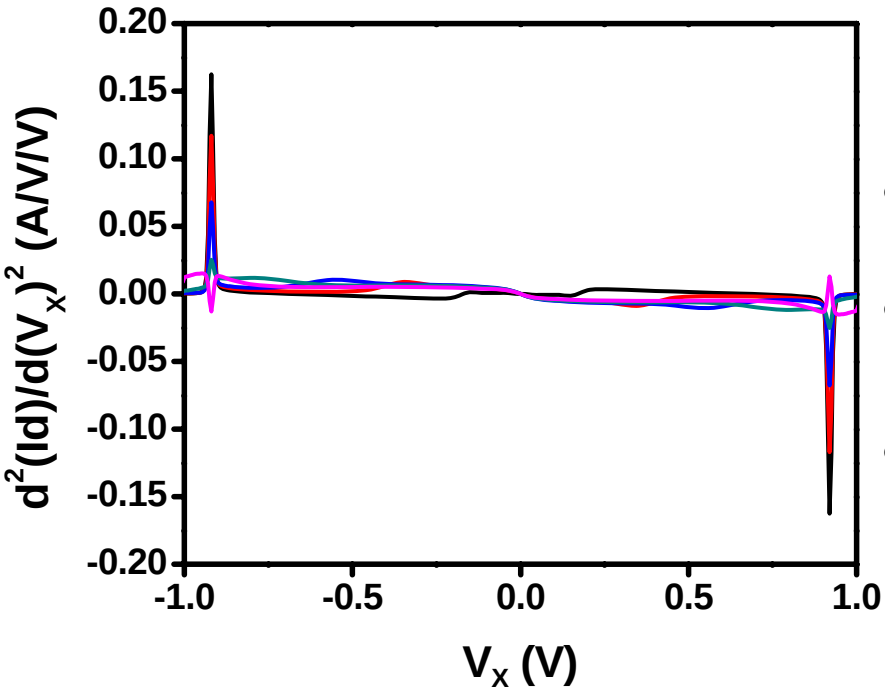
GST: 3rd derivative of I_d

PSP 101.0

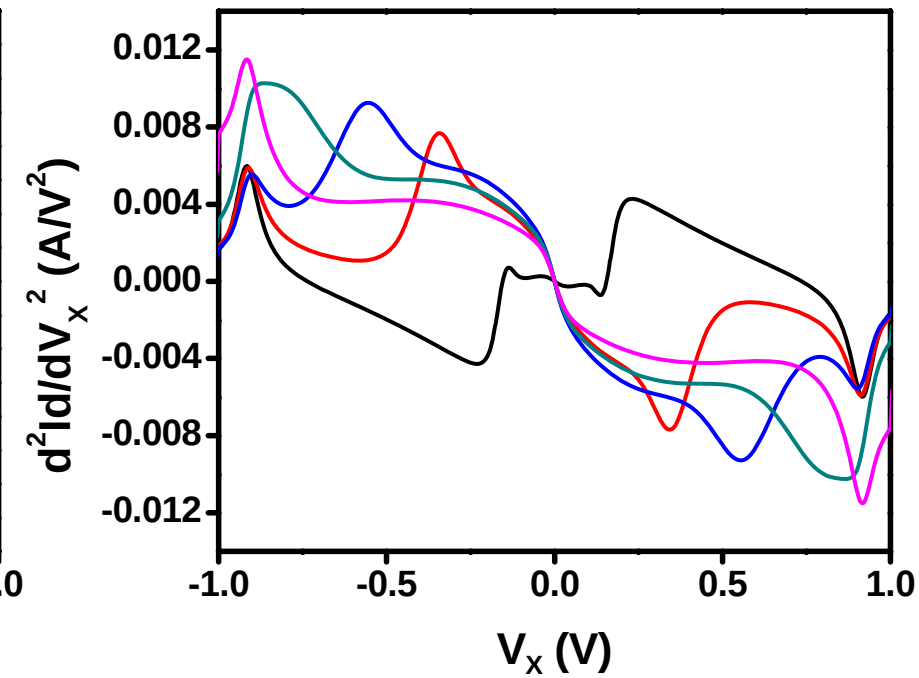




The Effect of V_{BS} Clamping: Gummel Symmetry Test

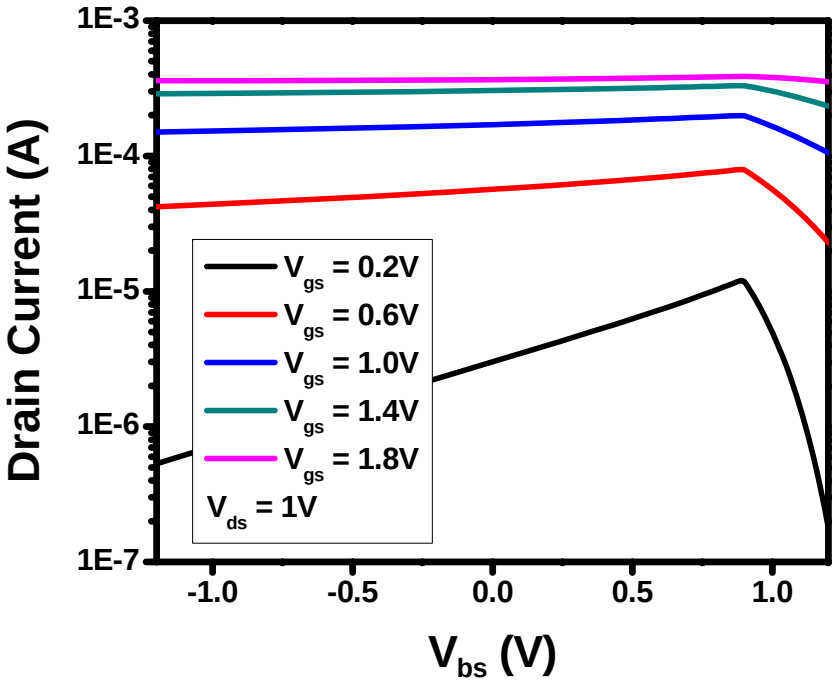


PSP 100.1

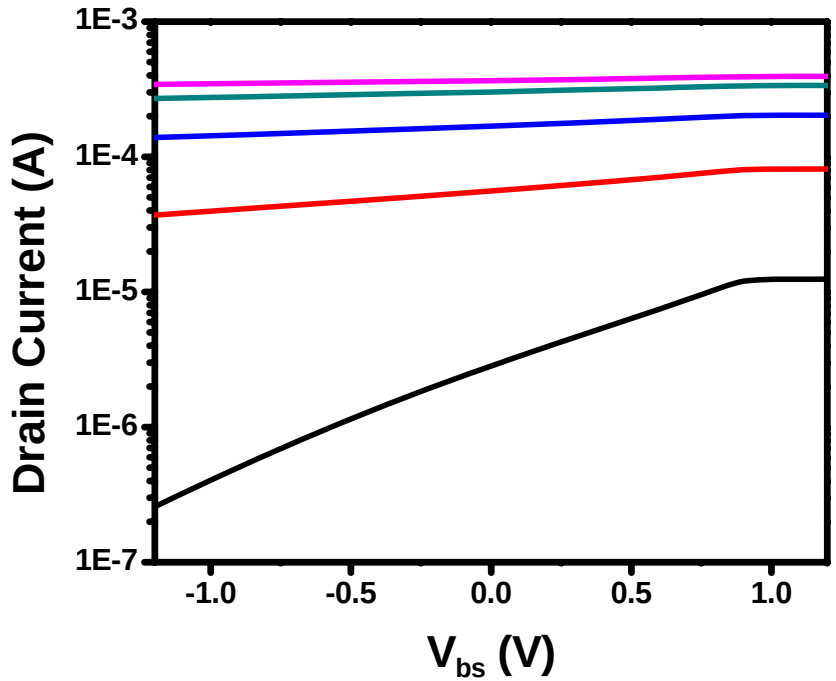


PSP 101.0

The Effect of V_{BS} Clamping: I_D vs. V_{BS}



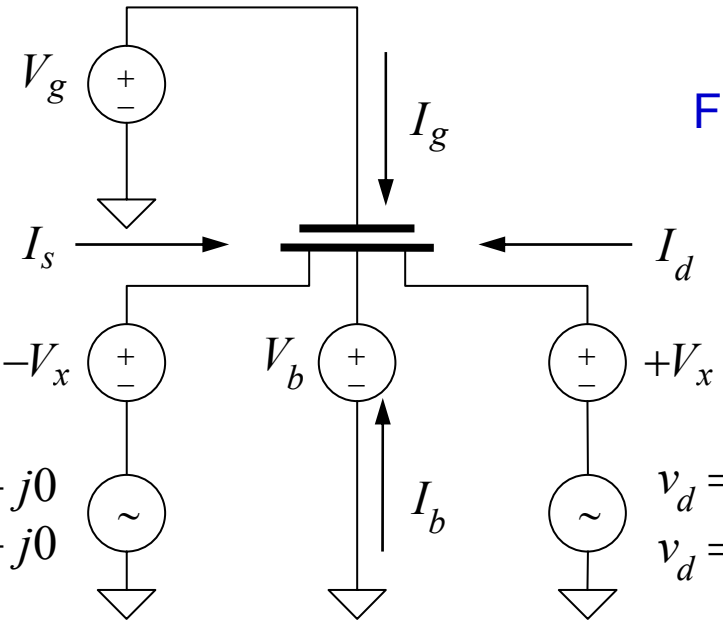
PSP 100.1



PSP 101.0

W/L = 10/10 (µm)

Modified Symmetry Test AC version



From C. McAndrew

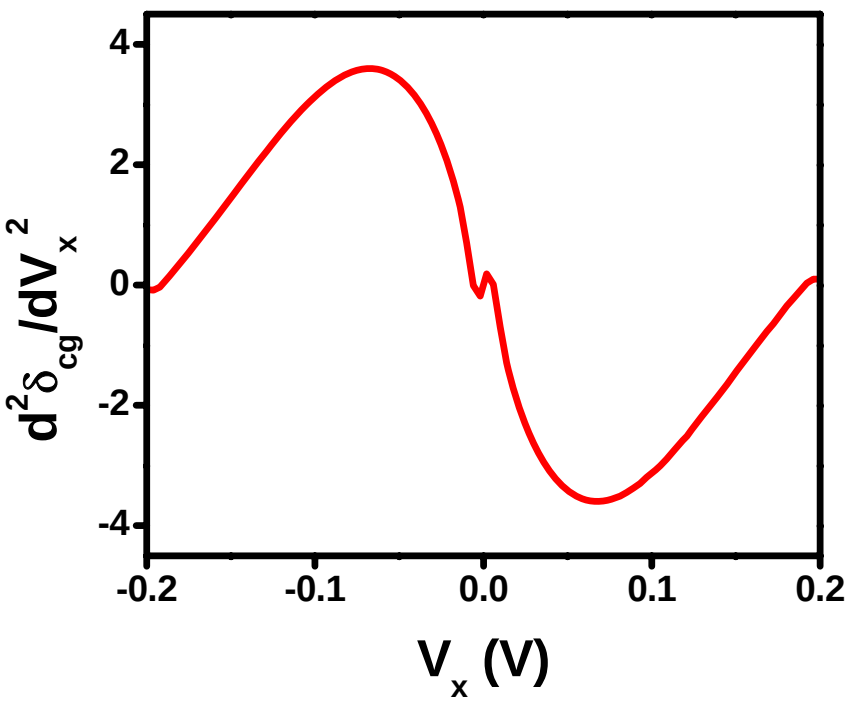
anti−phase $v_s = -1 + j0$
in−phase $v_s = -1 + j0$

$v_d = +1 + j0$ anti−phase
$v_d = -1 + j0$ in−phase

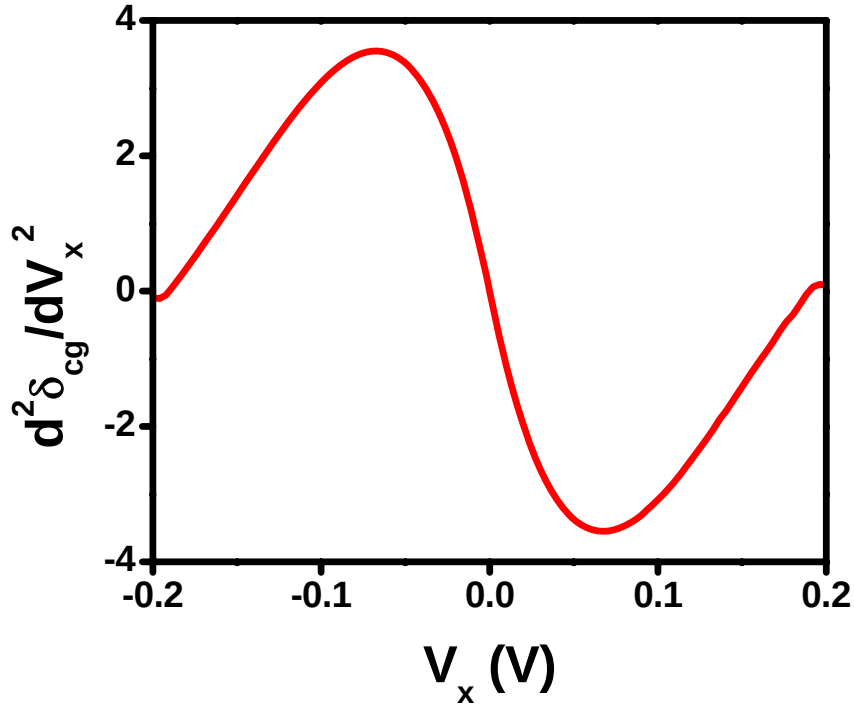
$$\delta_{cg} = \frac{i_{g-}}{i_{g+}} = \frac{C_{gs} - C_{gd}}{C_{gs} + C_{gd}} \qquad \delta_{cb} = \frac{i_{b-}}{i_{b+}} = \frac{C_{bs} - C_{bd}}{C_{bs} + C_{bd}}$$

$$\delta_{csd} = \frac{\left(i_{s-} + i_{d-}\right) + \left(i_{s+} - i_{d+}\right)}{\left(i_{s-} - i_{d-}\right) + \left(i_{s+} + i_{d+}\right)} = \frac{C_{ss} - C_{dd}}{C_{ss} + C_{dd}}$$

Modified Symmetry Test Results



PSP 100.1



PSP 101.0

W/L = 10/0.08 (µm)

Expanded Range of Some Parameters (Negative Values are Now Allowed)

- RSB: more flexible back-bias dependence of series resistance

$$\rho_b = \begin{cases} 1 + \mathbf{RSB} \cdot V_{sbx} & \text{for } \mathbf{RSB} \geq 0 \\ \dfrac{1}{1 - \mathbf{RSB} \cdot V_{sbx}} & \text{for } \mathbf{RSB} < 0 \end{cases}$$

- RSG: more flexible gate bias dependence of series resistance

$$\rho_{g,s} = \begin{cases} 1 + \mathbf{RSG} \cdot q_{is} & \text{for } \mathbf{RSG} \geq 0 \\ \dfrac{1}{1 - \mathbf{RSG} \cdot q_{is}} & \text{for } \mathbf{RSG} < 0 \end{cases}$$

- THESATB: more flexible dependence on substrate bias in saturation

$$\xi_{tb} = \begin{cases} 1 + \mathbf{THESATB} \cdot V_{sbx} & \text{for } \mathbf{THESATB} \geq 0 \\ \dfrac{1}{1 - \mathbf{THESATB} \cdot V_{sbx}} & \text{for } \mathbf{THESATB} < 0 \end{cases}$$

- THESATG: more flexible saturation region fits

$$\xi_{tg} = \begin{cases} 1 + \mathbf{THESATG} \cdot \omega_{sat} & \text{for } \mathbf{THESATG} \geq 0 \\ \dfrac{1}{1 - \mathbf{THESATG} \cdot \omega_{sat}} & \text{for } \mathbf{THESATG} < 0 \end{cases}$$

Further Details

- S0 is removed
- Induced gate noise frequency dependence is limited (S_{ig} does not rise beyond certain frequency).

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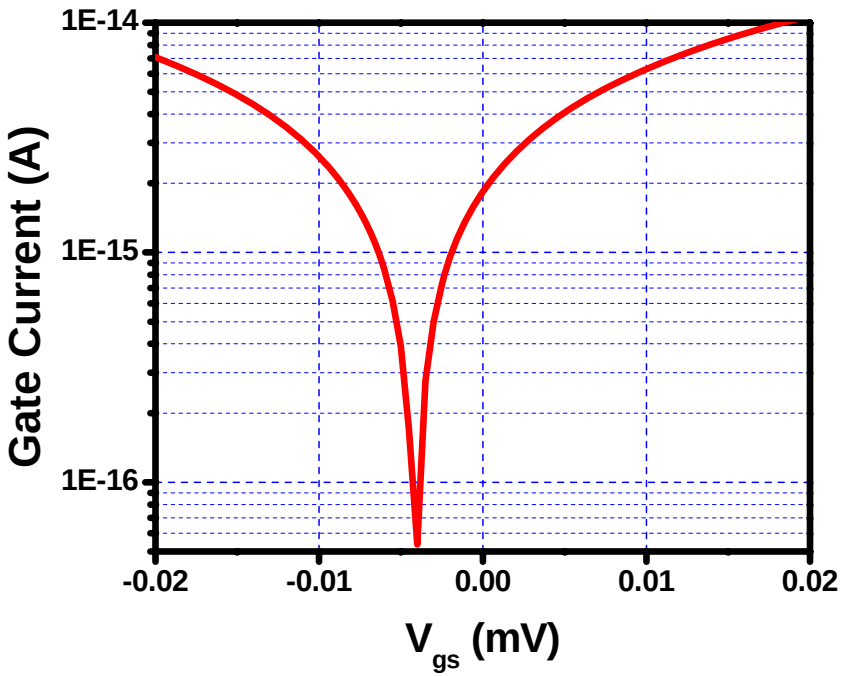
- **Gate Current**
- Extended Scaling
- Parameter Names
- Conclusions

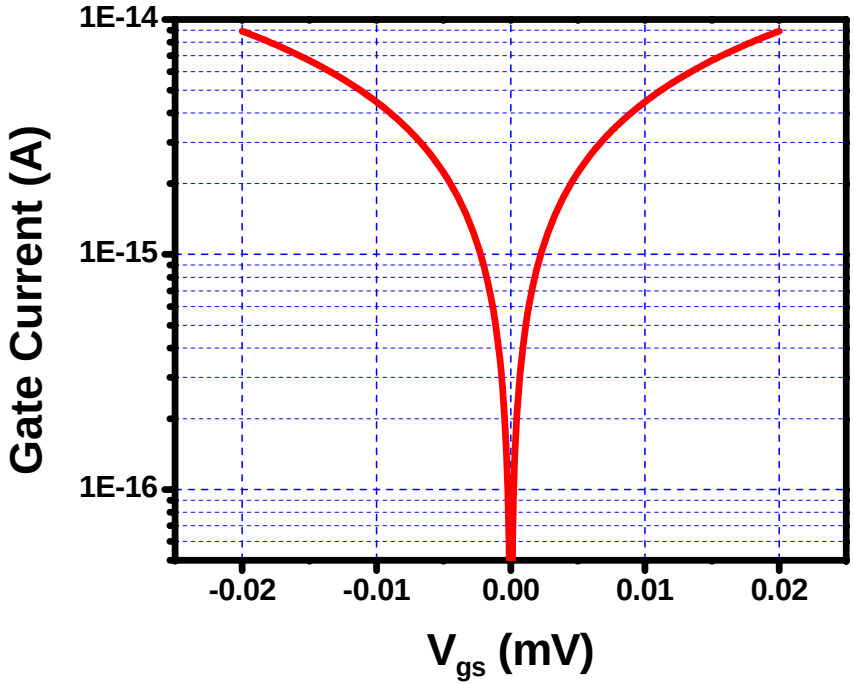
Gate Current Coding Problems (ADI, NEC)

- Numerical noise has been observed for some [unrealistic] values of parameters
- Unphysical shift of the $I_G(V_{GS})$ characteristics
- Fixed in PSP 101.0

Gate Current



PSP 100.1



PSP 101.0

W/L = 10/2 (µm)

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Mobility Model Improvement

- Improved short-channel I_D –V_G and g_m fits
  - Coulomb scattering term scaling (helps to decouple strong inversion and subthreshold regions)

$$CS = \left(CSO + CSL \cdot \left[\frac{L_{EN}}{L_E} \right]^{CSLEXP} \right) \cdot \left(1 + CSW \cdot \frac{W_{EN}}{W_E} \right) \cdot \left(1 + CSLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E} \right)$$

- More flexible V_B-dependence
  - New parameter **FETA** as an alternative to the use of **XCOR**
  - Two fitting styles: either use **FETA** and set **XCOR** =0 or set **FETA** =1 and use **XCOR**

$$E_{eff} = \left(q + \eta_\mu q_i \right) / \varepsilon; \qquad \eta_\mu = \frac{1}{2} \cdot \mathbf{FETA} \ \text{(NMOS)}; \ \eta_\mu = \frac{1}{3} \cdot \mathbf{FETA} \ \text{(PMOS)}$$

Geometry – Dependent Bulk Potential and Doping

$$\phi_B = \mathbf{DPHIB} + 2 \cdot \phi_T \cdot \ln\left(\frac{\mathbf{NEFF}}{n_i}\right)$$

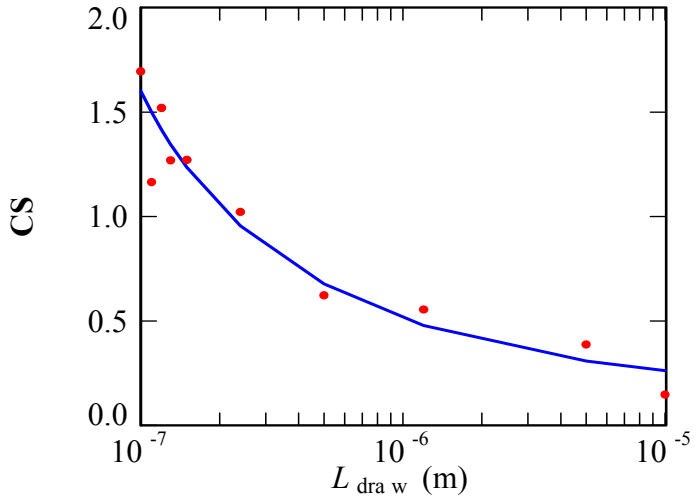
$$\mathbf{DPHIB} = \mathbf{DPHIBO} \cdot \left[1 + \mathbf{DPHIBL} \cdot \left(\frac{L_{EN}}{L_E}\right)^{\mathbf{DPHIBLEXP}}\right] \cdot \left(1 + \mathbf{DPHIBW} \cdot \frac{W_{EN}}{W_E}\right)\left(1 + \mathbf{DPHIBLW} \cdot \frac{W_{EN}}{W_E} \cdot \frac{L_{EN}}{L_E}\right)$$

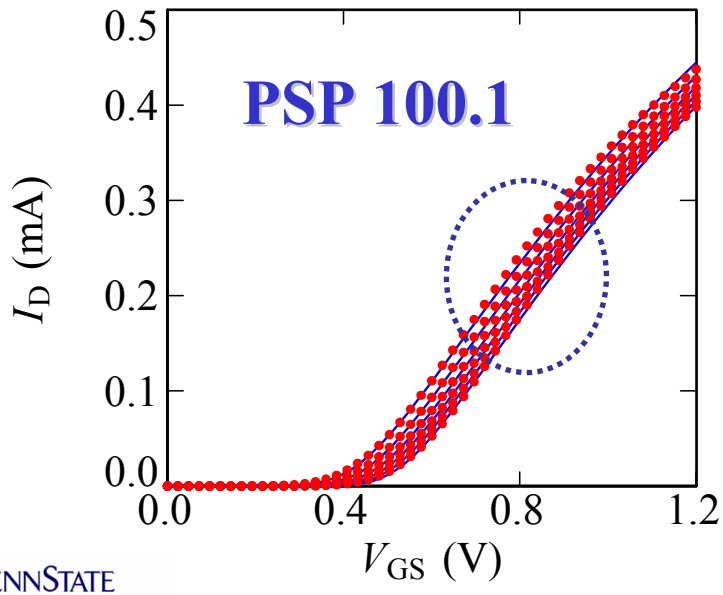
$$\mathbf{NEFF} = \mathbf{NSUB}(L, W) \cdot \left[1 - \mathbf{FOL1} \cdot \frac{L_{EN}}{L_E} - \mathbf{FOL2}\left(\frac{L_{EN}}{L_E}\right)^2\right]$$

- Picks up some functionalities originally placed in geometry dependence of lateral gradient factor.

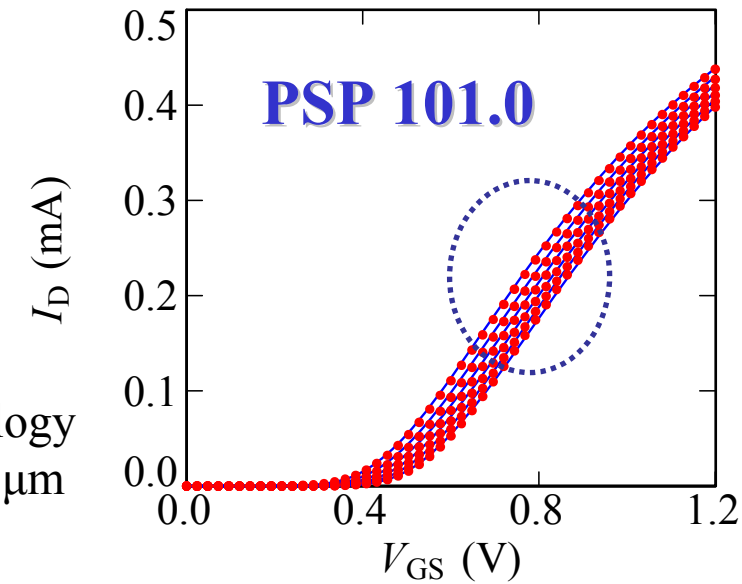
L-dependence of CS

- Improved short-channel $I_D - V_G$ and g_m fits
- Due to CS-scaling *and* introduction of DPHIB

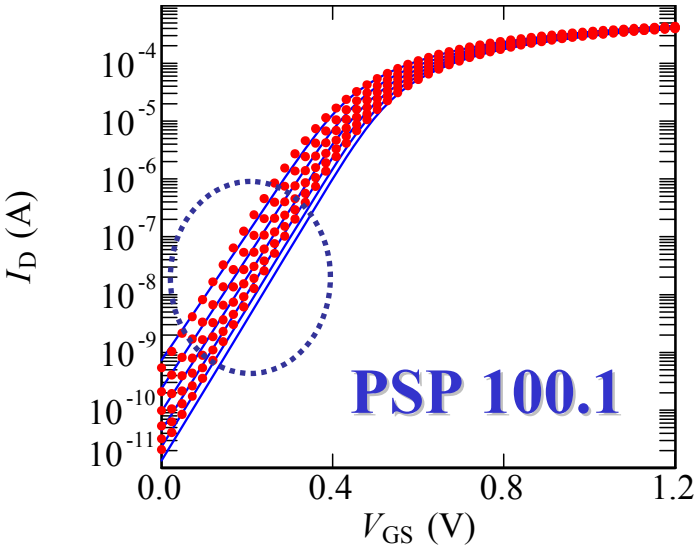


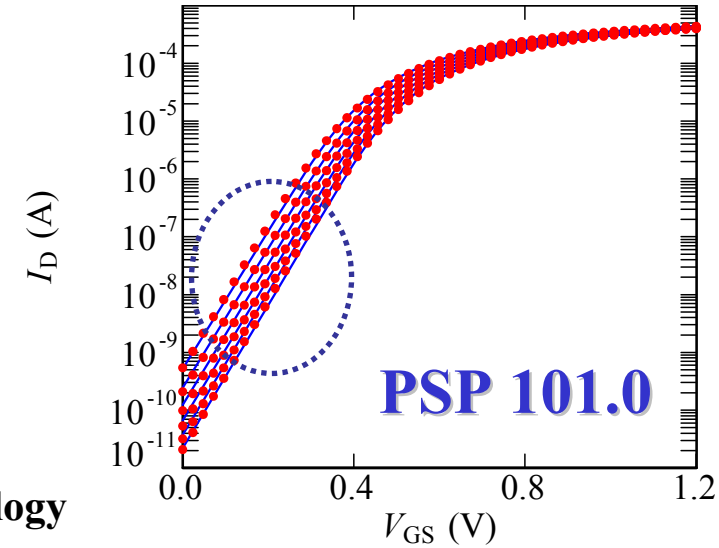


90 nm technology
W/L = 10/0.1 µm

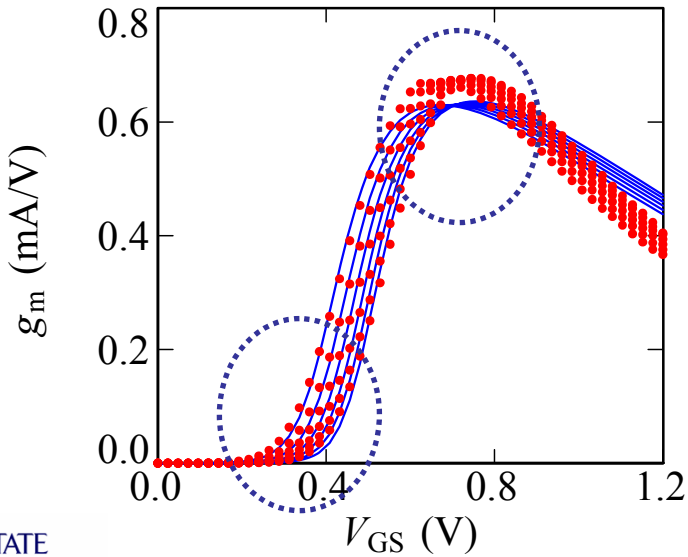


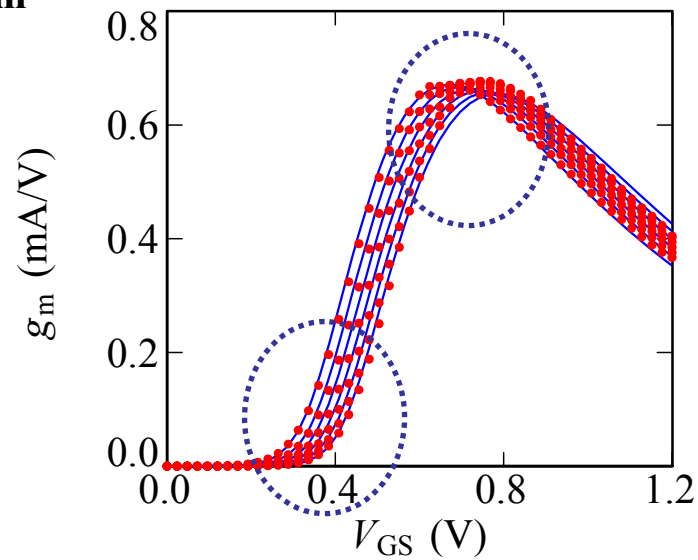
L-dependence of CS (cont.)





90 nm technology
W/L = 10/0.1 µm





Expanded Scaling

- Addition of LW term to **CT** improves accuracy of subthreshold ("OFF") current

$$\mathbf{CT} = \left(\mathbf{CTO} + \mathbf{CTL} \cdot \left[\frac{L_{EN}}{L_E} \right]^{\mathbf{CTLEXP}} \right) \cdot \left(1 + \mathbf{CTW} \cdot \frac{W_{EN}}{W_E} \right) \cdot \left(1 + \mathbf{CTLW} \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E} \right)$$

- Addition of LW term to **THESAT** improves modeling of "ON" current

$$\mathbf{THESAT} = \left(\mathbf{THESATO} + \mathbf{THESATL} \cdot \frac{G_{W,E}}{G_{P,E}} \cdot \left[\frac{L_{EN}}{L_E} \right]^{\mathbf{THESATLEXP}} \right) \cdot \left(1 + \mathbf{THESATW} \cdot \frac{W_{EN}}{W_E} \right) \cdot \left(1 + \mathbf{THESATLW} \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E} \right)$$

Expanded Scaling Contd.

- $G_{DS}(L)$ fit is improved by expanding L dependence of **ALP2**

$$\mathbf{ALP2} = \frac{\mathbf{ALP2L1} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{ALP2LEXP}}}{1 + \mathbf{ALP2L2} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{ALP2LEXP}+1}} \cdot \left(1 + \mathbf{ALP2W} \cdot \frac{W_{EN}}{W_E}\right)$$

- Scaling of back bias dependence of substrate current is improved by adding L dependence of **A4**

$$\mathbf{A4} = \mathbf{A4O} \cdot \left(1 + \mathbf{A4L} \cdot \frac{L_{EN}}{L_E}\right) \cdot \left(1 + \mathbf{A4W} \cdot \frac{W_{EN}}{W_E}\right)$$

Decoupled Geometry for Current and Charges (Freescale, STm, Jazz)

$$L_{\mathrm{E,CV}} = L + \Delta L_{\mathrm{PS}} - 2 \cdot \mathbf{LAP} + \mathbf{DLQ}$$

$$W_{\mathrm{E,CV}} = W + \Delta W_{\mathrm{OD}} - 2 \cdot \mathbf{WOT} + \mathbf{DWQ}$$

$$\mathbf{COX} = \varepsilon_{\mathrm{ox}} \cdot \frac{W_{\mathrm{E,CV}} \cdot L_{\mathrm{E,CV}}}{\mathbf{TOX}}$$

$$\mathbf{CGOV} = \varepsilon_{\mathrm{ox}} \cdot \frac{W_{\mathrm{E,CV}} \cdot \mathbf{LOV}}{\mathbf{TOXOV}}$$

Improves flexibility of DC and CV fits

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Parameter Names

- Zeros no longer occur in parameter names, to avoid confusion between zeros and "O"s. They are all replaced by "O"s.

- Some global parameter names have an additional "O" in their names in order to avoid duplicate names in the global and local model

Instance Parameters for JUNCAP2 in PSP

	source			drain		
SWJUNCAP	**AB**	**LS**	**LG**	**AB**	**LS**	**LG**
0	0	0	0	0	0	0
1	**ABSOURCE**	**LSSOURCE**	**LGSOURCE**	**ABDRAIN**	**LSDRAIN**	**LGDRAIN**
2	**AS**	**PS**	0	**AD**	**PD**	0
3	**AS**	**PS** $- W_{\mathrm{E}}$	W_{E}	**AD**	**PD** $- W_{\mathrm{E}}$	W_{E}

- SWJUNCAP=1: instance parameters as in PSP 100.1
- SWJUNCAP=2: instance parameters as in BSIM4, perMod=0
- SWJUNCAP=3: instance parameters as in BSIM4, perMod=1

Summary of Improvements in PSP 101.0

- Improved short-channel I_D –V_G and g_m fits
- Improved Gummel symmetry
- Full reciprocity of capacitances
- Improved forward-V_B behavior
- More flexible bias dependence of series resistance and saturation current
- More flexible geometry dependence for CV/IV fits
- Expanded scaling
- Binning (separate presentation)
- Synchronized junction instance parameters with BSIM
- Fixed minor bugs and numerical issues

Conclusions

- PSP 101.0 satisfies most requirements for standardization
- Several issues pointed out during model evaluation process and afterwards have been addressed
- We are looking for feedback