RF-MOSFET Model-Parameter Extraction with HiSIM

Workshop on Compact Modeling at MSM 2005

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Outline

1. Requirements for Parameter Extraction and MOSFET Model
2. Advantageous of Surface-Potential-Based Modeling
3. Core Model Parameters of HiSIM
5. Automatic Parameter Extraction with Genetic Algorithm (GA)
6. Automatic Extraction Results
7. Summary
Accuracy Requirement
(aiming at accurate reproduction of measurements)

I-V measurements

Derivatives

---

meas.
model
Predictability Requirement
(aiming at accurate prediction of unmeasured data)

Derivatives
(for down-scaled gate length)

1/f Noise
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Properties of a Surface-Potential-Based Model

\[ \phi_{S0} : \text{at source side} \]
\[ \phi_{SL} : \text{at drain side} \]

Surface-Potential \(\rightarrow\) Measure for All Device Features
Calculated Surface Potentials

Short-channel effects included in the $\phi_S$ calculation
Induced Charges on Nodes

\[
\begin{align*}
Q_I &= W \int_0^L Q_i(y) dy; \\
Q_B &= W \int_0^L Q_b(y) dy \\
Q_S &= W \int_0^L \left(1 - \frac{y}{L}\right) Q_i(y) dy; \\
Q_D &= W \int_0^L \frac{y}{L} Q_i(y) dy \\
Q_I &= Q_S + Q_D \\
Q_b(y) &= -qN_{sub} \times W_d = -\sqrt{\frac{2 \varepsilon_s q N_{sub}}{\beta}} \left\{ \beta \left( \phi_s(y) - V_{bs} \right) - 1 \right\}^{-\frac{1}{2}} \\
I_{ds} &= q \frac{W}{L} \int v Q_{id} dy
\end{align*}
\]

\[
C_{jk} = \frac{dQ_j}{dV_k}
\]

current  charge  capacitance
Valid Surface Potential for All Bias Conditions
Current Equations Based on Surface-Potential

**Drift-Diffusion Approximation**

\[
I_{ds} / \left( \frac{1}{\beta} \mu \frac{W}{L} \right) = C_{ox}(1+\beta V'_{G})(\phi_{SL} - \phi_{S0}) - \frac{\beta}{2} C_{ox}(\phi_{SL}^2 - \phi_{S0}^2)
- \frac{2}{3} \sqrt{\frac{2\varepsilon_s qN_{sub}}{\beta}} \left[ (\beta \phi_{SL} - 1)^{\frac{3}{2}} - (\beta \phi_{S0} - 1)^{\frac{3}{2}} \right]
+ \sqrt{\frac{2\varepsilon_s qN_{sub}}{\beta}} \left[ (\beta \phi_{SL} - 1)^{\frac{1}{2}} - (\beta \phi_{S0} - 1)^{\frac{1}{2}} \right]
\]

\[V'_G = V_{gs} - V_{fb} + (\Delta V_{th})\]

**Drift Approximation:**

\[
\phi_{S0} = 2\Phi_B = \frac{2}{\beta} \ln \left( \frac{N_{sub}}{n_i} \right) ; \quad \phi_{SL} = \phi_{S0} + V_{ds}
\]

\[
I_{ds} / \left( \mu \frac{W}{L} C_{ox} \right) = (V_G - 2\Phi_B - \frac{\sqrt{2\varepsilon_s qN_{sub}}}{C_{ox}} 2\Phi_B^{\frac{1}{2}}) V_{ds} - \left( \frac{1}{2} + \frac{\sqrt{2\varepsilon_s qN_{sub}}}{4C_{ox}} 2\Phi_B^{\frac{1}{2}} \right) V_{ds}^2
\]

\[\approx (V_G - V_{th}) V_{ds} - \frac{1}{2} V_{ds}^2\]

\[V_G = V_{gs} - V_{fb}\]
Low-Field Mobility Based on Surface Potential

\[ \frac{1}{\mu_0} = \frac{1}{\mu_{CB}} + \frac{1}{\mu_{PH}} + \frac{1}{\mu_{SR}} \]

- \(\mu_{CB}\) (Coulomb) = \(MUECB0 + MUECB1 \frac{Q_i}{q \times 10^{11}}\)

- \(\mu_{PH}\) (phonon) = \(\frac{MUEPH0}{(T/300\,K)} \times \frac{MUETMP}{E_{eff}} \times MUEPH1\)

- \(\mu_{SR}\) (surface roughness) = \(\frac{MUESR0}{E_{eff}} \times MUESR1\)

\[ E_{eff} = \frac{1}{\varepsilon_S} (NDEP \times Q_b + NINV \times Q_i) \]

\[ NINV = NINV - NINV D \times V_{ds} \]

Model Parameters

Charges

Universality:

- \(MUEPH1 = 0.3\)
- \(MUESR1 = 2.0\)
- \(NDEP = 1.0\)
- \(NINV = 0.5\)

Mobility is a function of charges → Surface Potentials
Modeling of RF Effects with HiSIM

Requires usually no additional model parameters!

- Higher-Order Derivatives
- Carrier-Response Delay for Non-Quasi-Static Effects (negligible below $f_T/3$)
- $1/f$ Noise (trap density: nearly universal when technology is mature)
- Thermal Noise

Accurate model parameter extraction from I-V measurements is sufficient. However, RF-effect measurements may be used for parameter fine tuning.
Thermal Noise Prediction without Parameters

Solid Lines: Model (HiSIM), Parameter Extraction from I-V Data
Symbols: Measurements of Thermal Noise

No Extra Model Parameters: Parameters for measured I-V data only

Key: Knowledge of correct channel-potential distribution makes modeling of RF-MOSFET phenomena simple.
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6. Automatic Extraction Results
7. Summary
<table>
<thead>
<tr>
<th>Device Parameters (11)</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOX</td>
<td>oxide thickness</td>
<td>m</td>
</tr>
<tr>
<td>XLD</td>
<td>gate-overlap length</td>
<td>m</td>
</tr>
<tr>
<td>XWD</td>
<td>gate-overlap width</td>
<td>m</td>
</tr>
<tr>
<td>XPOLYD</td>
<td>gate-poly overlap length</td>
<td>m</td>
</tr>
<tr>
<td>TPOLY</td>
<td>height of the gatepoly-Si</td>
<td>m</td>
</tr>
<tr>
<td>RS</td>
<td>source-contact resistance</td>
<td>V A⁻¹m</td>
</tr>
<tr>
<td>RD</td>
<td>drain-contact resistance</td>
<td>V A⁻¹m</td>
</tr>
<tr>
<td>NSUBC</td>
<td>substrate-impurity concentration</td>
<td>cm⁻³</td>
</tr>
<tr>
<td>NSUBP</td>
<td>maximumpocket concentration</td>
<td>cm⁻³</td>
</tr>
<tr>
<td>VFBC</td>
<td>flat-band voltage</td>
<td>V</td>
</tr>
<tr>
<td>LP</td>
<td>pocket penetration length</td>
<td>m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature Dependence (2)</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGTP1</td>
<td>bandgap narrowing</td>
<td>eVK⁻¹</td>
</tr>
<tr>
<td>BGTP2</td>
<td>bandgap narrowing</td>
<td>eVK⁻²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quantum Effect (3)</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>QME1</td>
<td>coefficient for quantum mechanical effect</td>
<td>V m</td>
</tr>
<tr>
<td>QME2</td>
<td>coefficient for quantum mechanical effect</td>
<td>V</td>
</tr>
<tr>
<td>QME3</td>
<td>coefficient for quantum mechanical effect</td>
<td>m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Poly Depletion (3)</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGD1</td>
<td>strength of poly depletion</td>
<td>V</td>
</tr>
<tr>
<td>PGD2</td>
<td>threshold voltage of poly depletion</td>
<td>V</td>
</tr>
<tr>
<td>PGD3</td>
<td>V_{ds} dependence of poly depletion</td>
<td>—</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channel-Length Modul. (3)</th>
<th>Description</th>
<th>—</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLM1</td>
<td>channel/contact junction condition</td>
<td>—</td>
</tr>
<tr>
<td>CLM2</td>
<td>coefficient for Q_B contribution</td>
<td>—</td>
</tr>
<tr>
<td>CLM3</td>
<td>coefficient for Q_I contribution</td>
<td>—</td>
</tr>
</tbody>
</table>
### Short Channel (7)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARL2</td>
<td>depletion width of channel/conta junction</td>
<td>m</td>
</tr>
<tr>
<td>SC1</td>
<td>short-channel coefficient 1</td>
<td>V⁻¹</td>
</tr>
<tr>
<td>SC2</td>
<td>short-channel coefficient 2</td>
<td>V⁻²</td>
</tr>
<tr>
<td>SC3</td>
<td>short-channel coefficient 3</td>
<td>V⁻²m</td>
</tr>
<tr>
<td>SCP1</td>
<td>short-channel coefficient 1 for pocket</td>
<td>V⁻¹</td>
</tr>
<tr>
<td>SCP2</td>
<td>short-channel coefficient 2 for pocket</td>
<td>V⁻²</td>
</tr>
<tr>
<td>SCP3</td>
<td>short-channel coefficient 3 for pocket</td>
<td>V⁻²m</td>
</tr>
</tbody>
</table>

### Mobility (16)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>MUECB0</td>
<td>Coulomb scattering</td>
<td>cm²V⁻¹s⁻¹</td>
</tr>
<tr>
<td>MUECB1</td>
<td>Coulomb scattering</td>
<td>cm²V⁻¹s⁻¹</td>
</tr>
<tr>
<td>MUEPH0</td>
<td>phonon scattering *** 0.3</td>
<td>cm²(V s)⁻¹(V cm)⁻¹</td>
</tr>
<tr>
<td>MUEPH1</td>
<td>phonon scattering</td>
<td>—</td>
</tr>
<tr>
<td>MUETMP</td>
<td>temperature dependence</td>
<td>—</td>
</tr>
<tr>
<td>MUESR0</td>
<td>surface-roughness scattering *** 2.0</td>
<td>—</td>
</tr>
<tr>
<td>MUESR1</td>
<td>surface-roughness scattering</td>
<td>—</td>
</tr>
<tr>
<td>NDEP</td>
<td>coefficient of effective-electric field *** 1.0</td>
<td>V⁻¹</td>
</tr>
<tr>
<td>NINV</td>
<td>coefficient of effective-electric field *** 0.5</td>
<td>—</td>
</tr>
<tr>
<td>NINVD</td>
<td>modification of NINV</td>
<td>—</td>
</tr>
<tr>
<td>BB</td>
<td>high-field-mobility degradation *** 2.0</td>
<td>—</td>
</tr>
<tr>
<td>VMAX</td>
<td>maximum saturation velocity</td>
<td>—</td>
</tr>
<tr>
<td>VOVER</td>
<td>velocity overshoot effect</td>
<td>cm⁻¹</td>
</tr>
<tr>
<td>VOVERP</td>
<td>Lg dependence of velocity overshoot</td>
<td>—</td>
</tr>
<tr>
<td>RPOCK1</td>
<td>resistance caused by the potential barrier</td>
<td>V⁻²A⁻¹m¹/²</td>
</tr>
<tr>
<td>RPOCK2</td>
<td>resistance caused by the potential barrier</td>
<td>—</td>
</tr>
</tbody>
</table>
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Manual Extraction: Basic Procedure

• Start from a long $L_{\text{gate}}$ transistor
  - extract basic technological parameters

• Use $V_{\text{th}}$ for rough extraction

• Use $I_{\text{ds}} - V_{\text{gs}}$ characteristics for exact extraction

• Final parameter extraction with short $L_{\text{gate}}$
  - fine tuning of parameters

For each group one additional transistor to check predictability
Manual Extraction: Remarks

- **Separate Extraction Programs**
  (Possible due to low parameter interdependence)
  - quantum-mechanical effects
  - gate-poly depletion effects

- **Local Optimizations**
  (Physical parameters: affected range of measured data is known)
  - start with default parameter values (often nearly optimal)
  - observe the valid optimization region
  - max and min values of the physical parameters
  - stick to correct optimization sequence

- **Repeat Extraction Procedures**
  to obtain increasingly reliable device parameter values
  
  \( (NSUBS, NSUBP, LP \text{ etc.}) \)
(1) Device Parameters + Quantum + Poly Depletion + Short-Channel Effects

(2) Device + Low-Field Mobility

(3) All Mobility Parameters
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Principle Extraction with Genetic Algorithm
(Parameters are Treated as Genes in Chromosomes)

(a) Initial Population

(b) Crossover & Mutation

(c) Optimized Population

Advantages:
• Total optimization is possible.
• No initial parameter set is required.
• No knowledge about models is required.
### Device

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<td>gate-overlap width</td>
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<tr>
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<td>substrate-impurity concentration</td>
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<tr>
<td>NSUBP</td>
<td>maximum pocket concentration</td>
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<td>VFBC</td>
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<td>LP</td>
<td>pocket penetration length</td>
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### Short Channel

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<th>Short Channel</th>
<th>Description</th>
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<tbody>
<tr>
<td>PARL2</td>
<td>depletion width: channel/contact</td>
</tr>
<tr>
<td>SC1</td>
<td>short-channel coefficient 1</td>
</tr>
<tr>
<td>SC2</td>
<td>short-channel coefficient 2</td>
</tr>
<tr>
<td>SC3</td>
<td>short-channel coefficient 3</td>
</tr>
<tr>
<td>SCP1</td>
<td>pocket short-channel coefficient 1</td>
</tr>
<tr>
<td>SCP2</td>
<td>pocket short-channel coefficient 2</td>
</tr>
<tr>
<td>SCP3</td>
<td>pocket short-channel coefficient 3</td>
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### Mobility

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<tr>
<td>MUECB0</td>
<td>Coulomb scattering</td>
</tr>
<tr>
<td>MUECB1</td>
<td>Coulomb scattering</td>
</tr>
<tr>
<td>MUEPH0</td>
<td>phonon scattering <strong>0.3</strong></td>
</tr>
<tr>
<td>MUEPH1</td>
<td>phonon scattering</td>
</tr>
<tr>
<td>MUETMP</td>
<td>temperature dependence</td>
</tr>
<tr>
<td>MUESR0</td>
<td>surface-roughness scattering <strong>2.0</strong></td>
</tr>
<tr>
<td>MUESR1</td>
<td>surface-roughness scattering</td>
</tr>
<tr>
<td>NDEP</td>
<td>effective-electric field <strong>1.0</strong></td>
</tr>
<tr>
<td>NINV</td>
<td>effective-electric field <strong>0.5</strong></td>
</tr>
<tr>
<td>NINVD</td>
<td>modification of NINV</td>
</tr>
<tr>
<td>BB</td>
<td>high-field mobility <strong>2.0</strong></td>
</tr>
<tr>
<td>VMAX</td>
<td>saturation velocity</td>
</tr>
<tr>
<td>VO</td>
<td>velocity overshoot</td>
</tr>
<tr>
<td>VOVERP</td>
<td>velocity overshoot</td>
</tr>
<tr>
<td>RPOCK1</td>
<td>pocket resistance</td>
</tr>
<tr>
<td>RPOCK2</td>
<td>pocket resistance</td>
</tr>
</tbody>
</table>

- **Fixed (in basic extraction)**
- **Red**: Group A (6)
- **Green**: Group B (26)
2-Stage Extraction Procedure

[Stage 1]
Parameter Group A: $a_1, a_2, \ldots$
Surface Potential
Simulated Device Performance
Measurements A

[Stage 2]
Parameter Group B: $b_1, b_2, \ldots$
Surface Potential
Simulated Device Performance
Measurements A+B
Error is small?
YES
Error is small?
YES
Stop
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2-Stage in Comparison to 1-Stage Extraction

![Graph showing Fitness vs. Evaluations (x10000)]
I-V Results for Long Channel Transistor

$L_g = 10 \mu m$

$V_{ds} = 0.1 V$

$V_{bs} = 0.0 V$
-0.5 V
-1.0 V
-1.5 V

$V_{gs} (V)$

$log (I_{ds}) (A)$

Meas

HiSIM

$V_{bs} = 0.0 V$

$V_{gs} = 1.5 V$

$V_{gs} = 1.0 V$

$V_{gs} = 0.5 V$

$V_{gs} = 0.0 V$

$V_{ds} (V)$

$I_{ds} (A)$
I-V Results for Short Channel Transistor

$L_g=0.11\mu m$

- $V_{ds}=0.1V$
- $V_{bs}=0.0V$
- $V_{bs}=-0.5V$
- $V_{bs}=-1.0V$
- $V_{bs}=-1.5V$

Measurements (Meas) vs HiSIM Simulations
## Error Comparison

### Devices used for Extraction

<table>
<thead>
<tr>
<th>$L_g (\mu m)$</th>
<th>0.11</th>
<th>0.13</th>
<th>0.5</th>
<th>2.0</th>
<th>10.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Err. (%)</td>
<td>0.93</td>
<td>0.79</td>
<td>0.41</td>
<td>0.62</td>
<td>0.74</td>
</tr>
<tr>
<td>Max Err. (%)</td>
<td>2.59</td>
<td>2.52</td>
<td>1.51</td>
<td>1.69</td>
<td>2.02</td>
</tr>
<tr>
<td>Min Err. (%)</td>
<td>-2.51</td>
<td>-2.52</td>
<td>-1.86</td>
<td>-2.25</td>
<td>-2.71</td>
</tr>
</tbody>
</table>

### Devices not used for Extraction

<table>
<thead>
<tr>
<th>$L_g (\mu m)$</th>
<th>0.12</th>
<th>0.3</th>
<th>1.0</th>
<th>5.0</th>
<th>15.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Err. (%)</td>
<td>0.79</td>
<td>0.49</td>
<td>0.50</td>
<td>0.71</td>
<td>0.75</td>
</tr>
<tr>
<td>Max Err. (%)</td>
<td>2.60</td>
<td>1.94</td>
<td>1.43</td>
<td>1.90</td>
<td>2.06</td>
</tr>
<tr>
<td>Min Err. (%)</td>
<td>-2.56</td>
<td>-1.39</td>
<td>-2.06</td>
<td>-2.60</td>
<td>-2.75</td>
</tr>
</tbody>
</table>

Error = \( \frac{(I_{ds,\text{model}} - I_{ds,\text{meas}})}{I_{ds,\text{meas}}} \)
Reliability Test of GA Extraction: Group A

Group A

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Error rate</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$vfbc$</td>
<td>0.88%</td>
<td>0.37%</td>
</tr>
<tr>
<td>$nsubc$</td>
<td>0.46%</td>
<td>0.04%</td>
</tr>
<tr>
<td>$muecb0$</td>
<td>4.58%</td>
<td>3.01%</td>
</tr>
<tr>
<td>$muecb1$</td>
<td>10.5%</td>
<td>10.3%</td>
</tr>
<tr>
<td>$mueph1$</td>
<td>5.06%</td>
<td>0.24%</td>
</tr>
<tr>
<td>$muesr1$</td>
<td>2.74%</td>
<td>0.82%</td>
</tr>
</tbody>
</table>

Error = \( \frac{(Parameter_{GA} - Parameter_{Manual})}{Parameter_{Manual}} \)
Reliability Test of GA Extraction: Group B

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Error Rate</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>xld*</td>
<td>—</td>
<td>33.6%</td>
</tr>
<tr>
<td>nsubp*</td>
<td>0.24%</td>
<td>0.03%</td>
</tr>
<tr>
<td>scp1</td>
<td>35.0%</td>
<td>4.78%</td>
</tr>
<tr>
<td>scp2*</td>
<td>—</td>
<td>26.8%</td>
</tr>
<tr>
<td>scp3*</td>
<td>146%</td>
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* : extracted with log scale

Parameters with small sensitivity

Large error (deviation) in comparison to manual extraction
Summary

- HiSIM enables easy and reliable parameter extraction, due to low parameter interdependence.

- The capacitance model is automatically self-consistent with the I-V model and free from additional parameters.

- Reproduction of RF-related phenomena requires (almost) no additional model parameters. Model parameters determined from I-V characteristics are usually sufficient.

- HiSIM’s parameter extraction can be automated on the basis of a genetic-algorithm approach, delivering parameter sets of the same or better quality than the human expert.
Parameter List-1

Device Parameters (13)
- TOX: oxide thickness
- XLD: gate-overlap length
- XWD: gate-overlap width
- TPOLY: poly-Si height
- RS: source resistance
- RD: drain resistance
- NSUBC: substrate conc.
- NSUBP: pocket conc.
- LP: pockcet extension length
  - NSUBP0: shadowing effect
- NSUBPW:
  - NPEXT: pocket tail
  - LPEXT: tail extension

STI Effect (4)
- WSTI: STI width
- NSTI: impurity conc.
- VTHSTI: threshold voltage
- VSCSTI: short-channel effect

Material Features (4)
- EG0: bandgap
- VFB: flat-band voltage
- VBI: built-in potential
- VMAX: maximum velocity

Quantum Effect (3)
- QME1: Vgs depend
- QME2: minimum ∆Tox
- QME3: subthreshold

Temperature Dependent (4)
- BGTMP1: bandgap 1
- BGTMP2: bandgap 2
- MUETMP: mobility
- VTMP: velocity

Poly-Dep Effect (4)
- PGD1: strength
- PGD2: threshold voltage
- PGD3: Vds dependence
  - PGD4: length dependence

Noise Characteristics (2)
- NFALP: 1/f noise due to mobility
- NFTRP: trap density for 1/f
# Parameter List-2

## Short-Channel Effects (11)
- PARL2: depletion width
- SC1: strength
- SC2: DIBL
- SC3: vertical profile
- SCP1: SC1 of pocket
- SCP2: SC2 of pocket
- SCP3: SC3 of pocket
  - SCP21: DLBL reduction
  - SCP22: threshold for reduction
- BS1: vertical inhomogeneity
- PTHROU: subthreshold

## Narrow-Channel Effects (2)
- WFC: Qb change
- WVTH0: Vth shift

## MobilitySmall Geometry (3)
- WL0: size for small
- WL1: correction
- WLP:

## Mobility (19)
- MUECB0: Coulomb
- MUECB1:
- MUEPH0: phonon (0.3)
- MUEPH1:
  - MUEPHW: STI stress
  - MUEPWP:
  - MUEPHL: length dependence
  - MUEPLP:
- MUESR0: surface roughness (2.0)
- MUESR1:
  - MUESRW: STI stress
  - MUESWP:
  - MUESRL: inversion thickness
  - MUESLP:
  - MUEPHS: small size
  - MUEPSP:
- NDEP: Qb contribution (1.0)
- NINV: Qi contribution (0.5)
- BB: high field (2.0)
Parameter List-3

Channel Length Modul (3)
- CLM1: junction
- CLM2: $Q_b$ contribution
- CML3: $Q_i$ contribution

Pocket Resistance (4)
- RPOCK1:
- RPOCK2:
- RPOCH1:
- RPOCH2:

Velocity (2)
- VOVER: overshoot
- VOVERP:

Substrate Current (4)
- SUB1:
- SUB2:
- SUB3:
- SUB4:

Gate Current (14)
- GLEAK1: gate to channel
- GLEAK2:
- GLEAK3:
- GLEAK4:
- GLEAK5:
- GLEAK6:
- GLKS1: gate to source
- GLKS2:
- GLKS3:
- GLKD1: gate to drain
- GLKD2:
- GLKD3:
- GLKB1: gate to bulk
- GLKB2:

Diode (11)
- JS0:
- JS0SW:
- XTI:
- NJS:
- NJSW:
- CJ:
- CJSW:
- CJSWG:
- MJ:
- MJSW:
- MJSWG

GIDL Current (3)
- GIDL1:
- GIDL2:
- GIDL3:

Totally 115 (78) Model Parameters