

Nanotech

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: *Bulk models*

« *Dynamic charge sharing modeling for surface potential based models* »

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Outline

- Introduction
- Background
- 45nm data
- Charge Sharing
- Conclusion



Outline

- **Introduction**
Motivation and objectives
- **Background**
Body effect / Back bias polarization
Surface potential based models
- **Body effect characterization on 45nm node data**
Gate Length effect
Drain Voltage effect
- **Modeling: Dynamic charge sharing**
Constant charge sharing / V_{th} based models
Model description and validation
- **Conclusion**



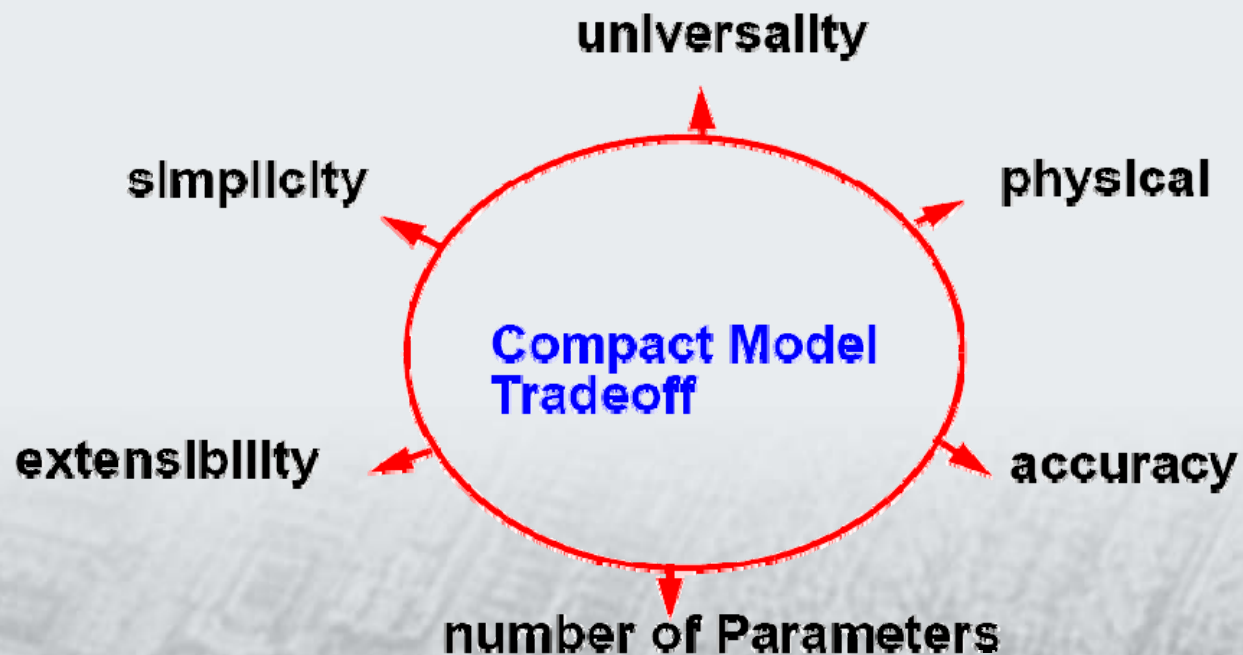
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Compact models

- are analytical models developed for Integrated Circuit (I.C.) simulations.
- require a tradeoff between :



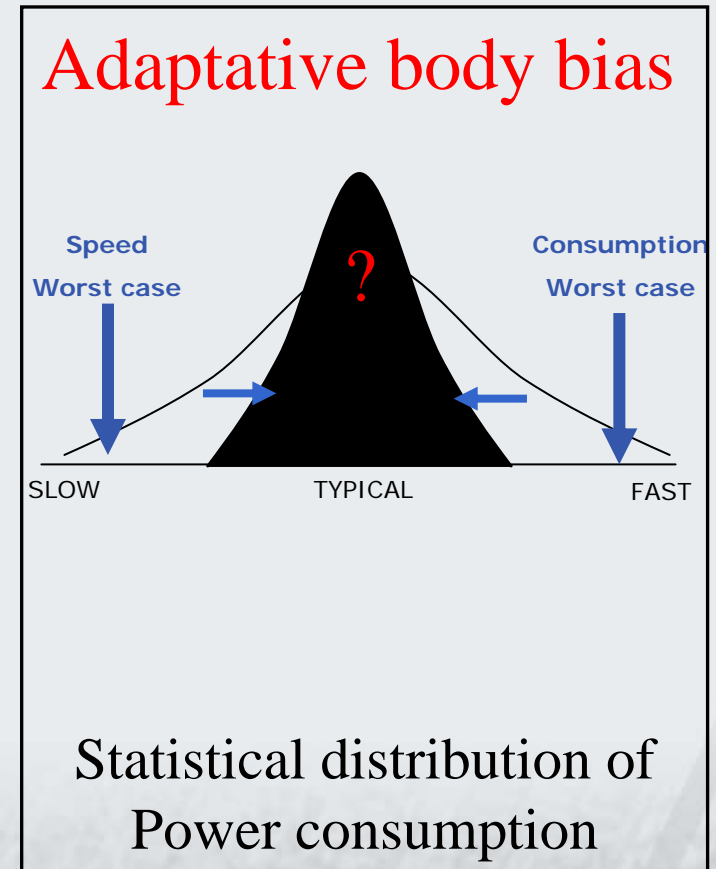
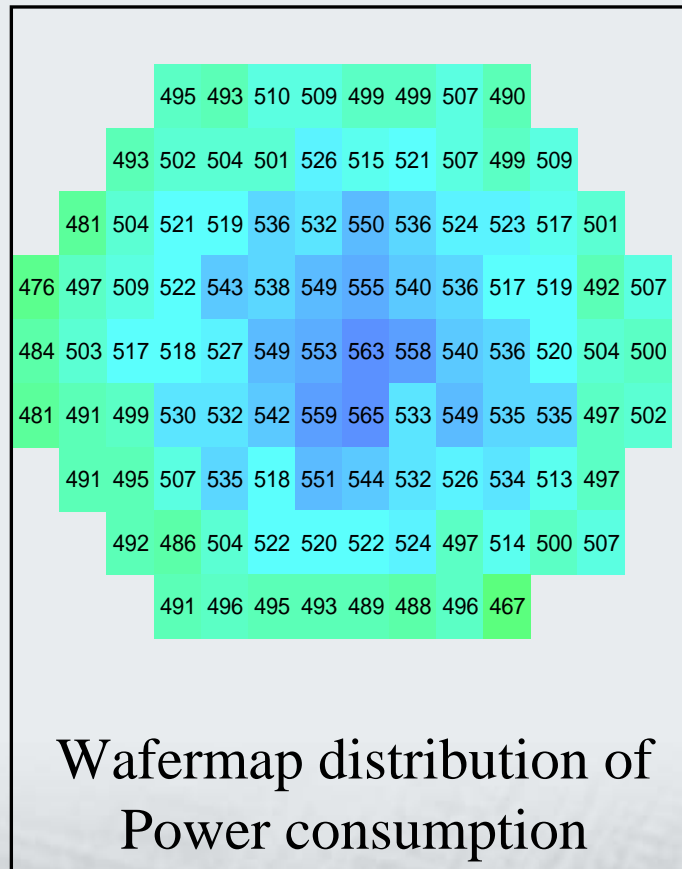


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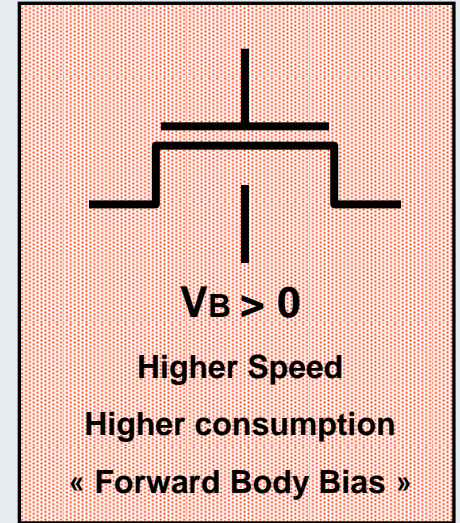
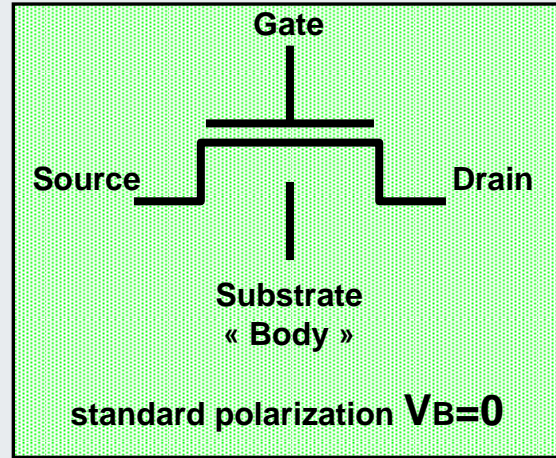
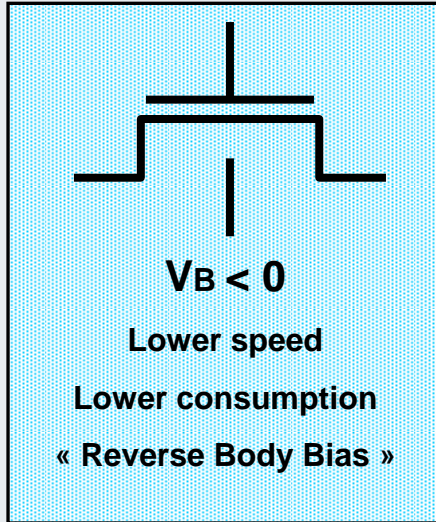
Motivation (1/2)

- **Designer request: how to boost devices?**



Motivation (2/2)

• Adaptative body biasing



Speed/Consumption

RBB

Reducing leakage power

FBB

Boost performance

V_B

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Objectives

- **Compact modeling requirements:**
 - Objectives:
 - 1) Characterization of Back bias effects
 - 2) Back bias effects incorporation for the modeling of state of the art devices
 - 3) Physical based approach for surface potential based models

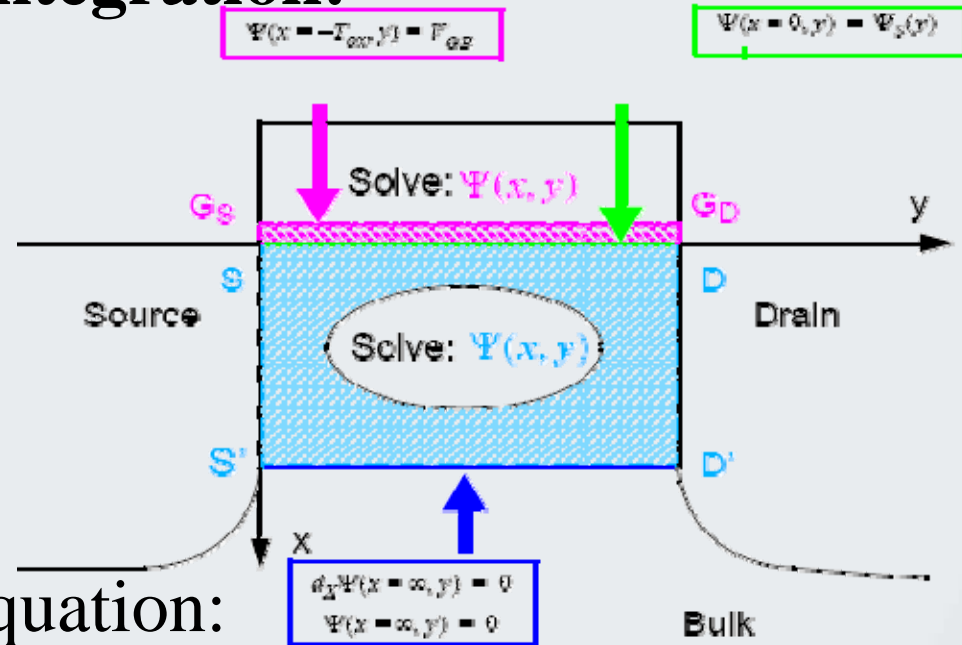
Surface potential based models

- Poisson equation integration:

$$\frac{\partial^2 \psi}{\partial x^2} = -\frac{q}{\epsilon_{Si}} (p(x) - n(x) - N_a)$$



Surface potential equation:



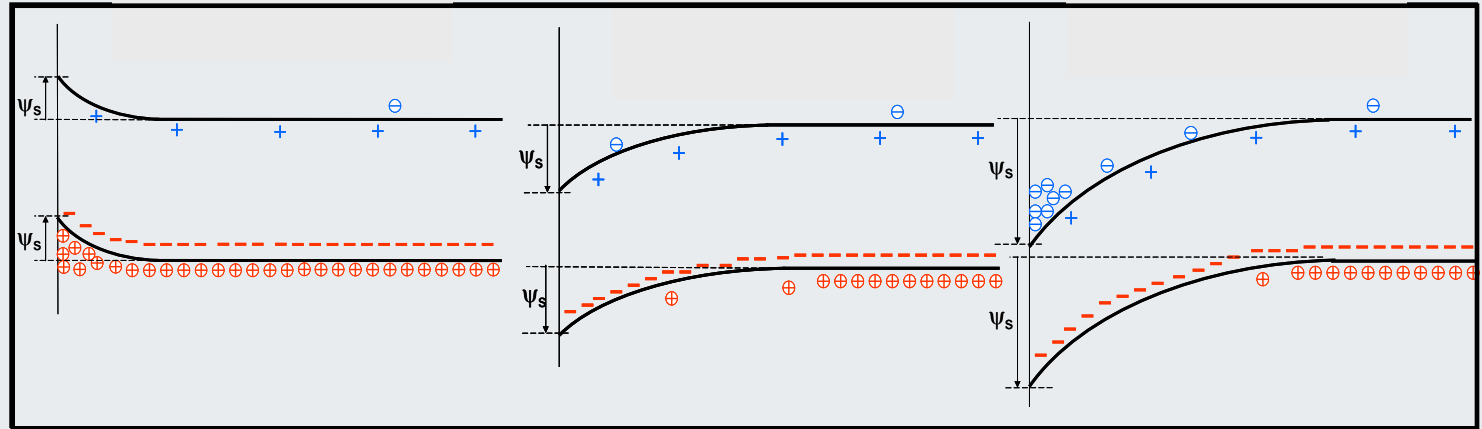
$$(V_G - V_{fb} - \psi_S)^2 = \gamma^2 \left[\exp\left(\frac{-2\Phi_F}{\Phi_T}\right) \left(\underbrace{\Phi_T \cdot e^{\frac{\psi_S(y) - V(y)}{\Phi_T}} - \psi_S(y) - \Phi_T \cdot e^{\frac{-V(y)}{\Phi_T}}}_{\text{contribution des électrons}} \right) + \underbrace{\psi_S(y)}_{\text{contribution des charges fixes}} + \Phi_T \left(\underbrace{e^{\frac{-\psi_S(y)}{\Phi_T}} - 1}_{\text{contribution des trous}} \right) \right]$$

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Surface potential based models

- One master equation suitable for each region



Accumulation Region

$$\psi_s < 0$$

Depletion Region

$$0 < \psi_s < 2\Phi_F$$

Inversion Region

$$\psi_s > 2\Phi_F$$

$$(V_G - V_{fb} - \psi_s)^2 = \gamma^2 \exp\left(-\frac{2\Phi_F}{\Phi_T}\right) \left[\underbrace{\Phi_T e^{\frac{\psi_s(y) - V(y)}{\Phi_T}} - \psi_s(y) - \Phi_T e^{-\frac{V(y)}{\Phi_T}}}_{\text{INVERSION}} + \underbrace{\psi_s(y)}_{\text{DEPLETION}} + \underbrace{\Phi_T \left(e^{-\frac{\psi_s(y)}{\Phi_T}} - 1 \right)}_{\text{ACCUMULATION}} \right]$$

- Replacing Vth-based models because no smooting functions between different regions

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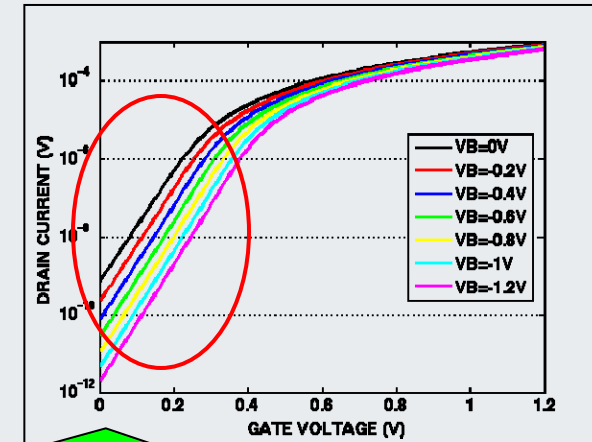
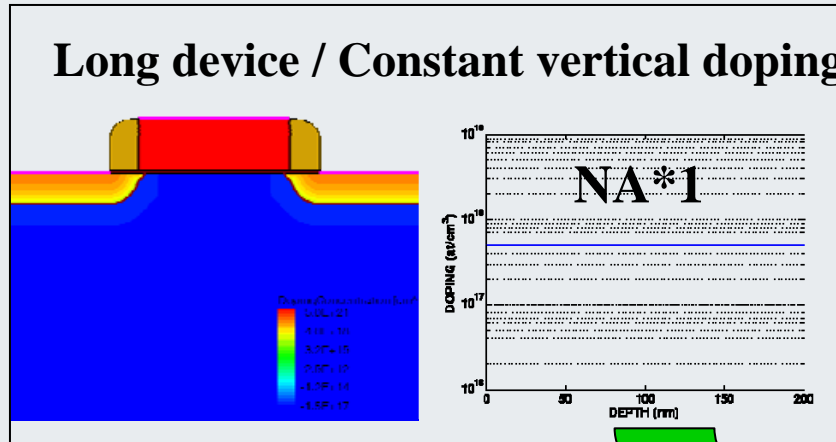


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What is the body effect?

- **Ideal constant doping - Long device (10 μ m):**



Body effect :
 sensitivity of V_{th} (subthreshold region) to back bias



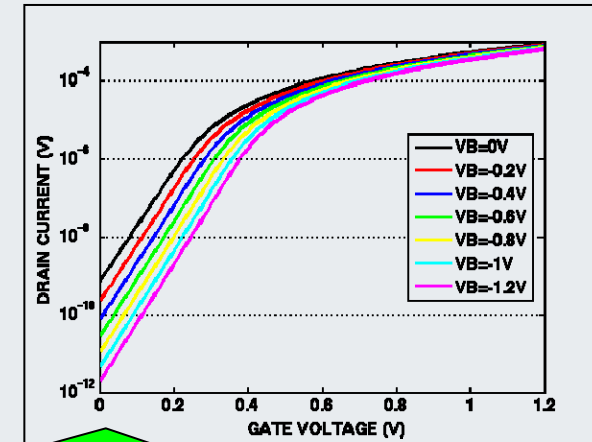
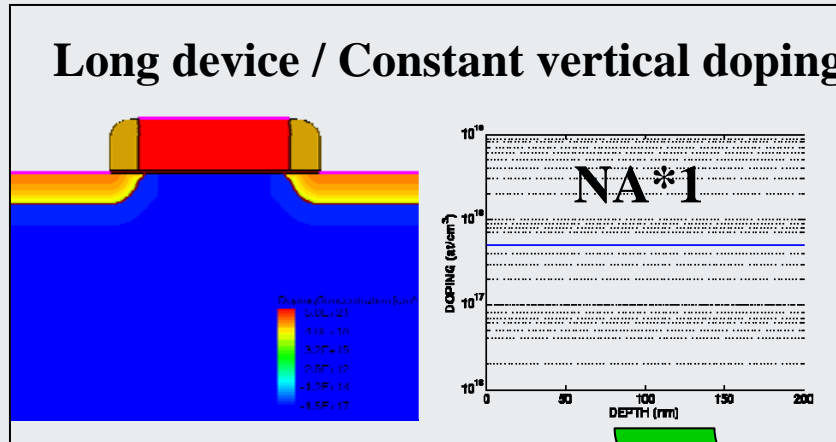


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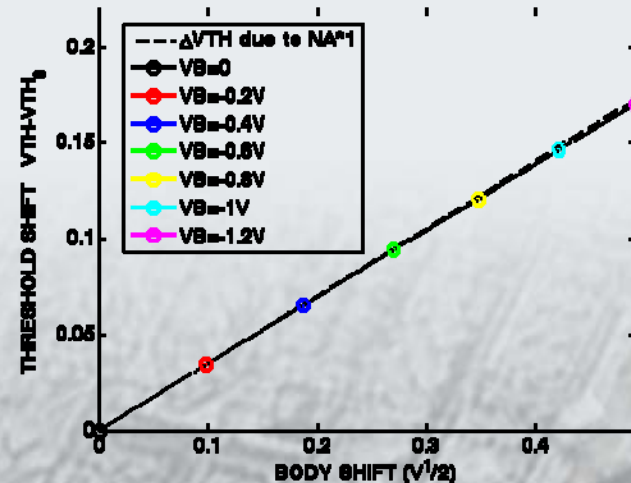
Body effect signature

- **Ideal constant doping - Long device (10μm):**



$$\Delta V_{TH} = V_{TH} - V_{TH0} = \gamma \left(\sqrt{2\Phi_F + V_{sb}} - \sqrt{2\Phi_F} \right)$$

Linear body signature





Outline

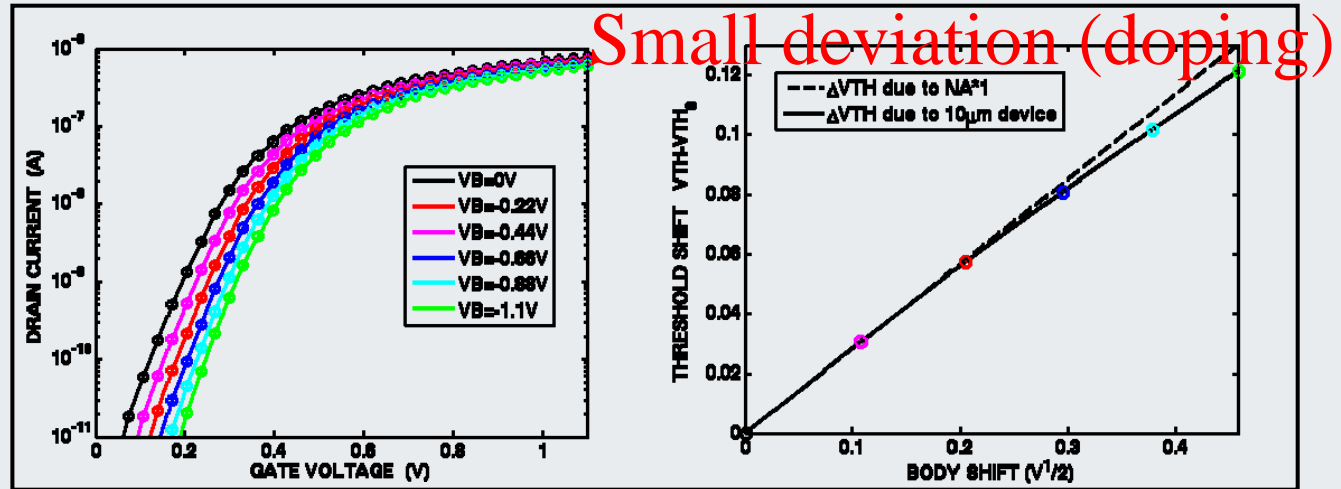
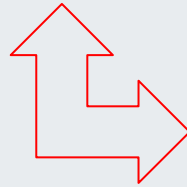
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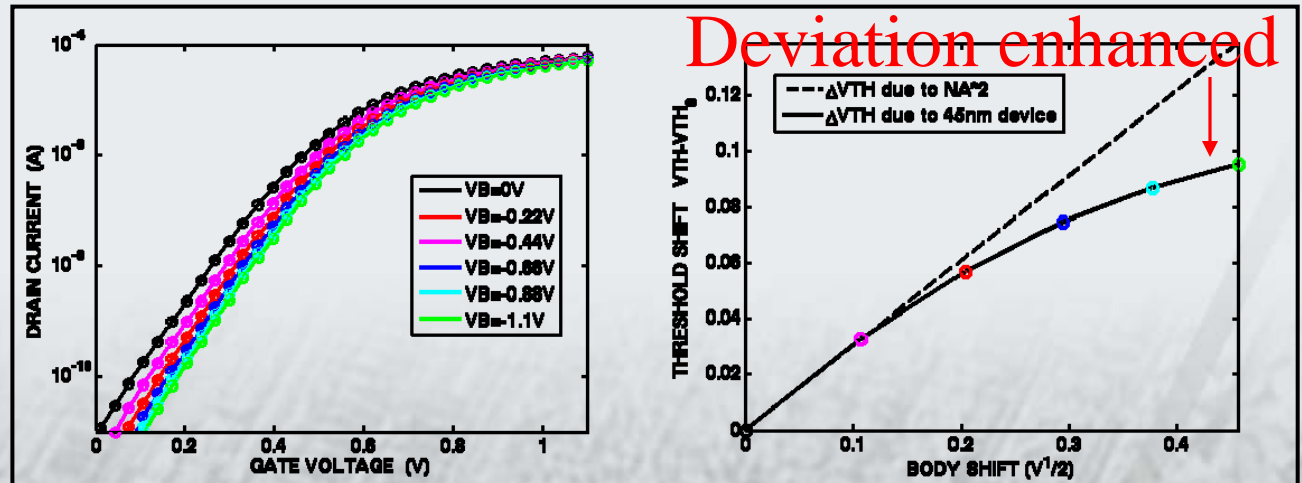
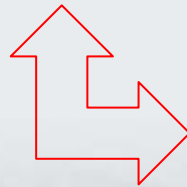
45nm measurements Id-Vg: body effect signature

- Long to short channel

Lgate = 10μm



Lgate = 45nm



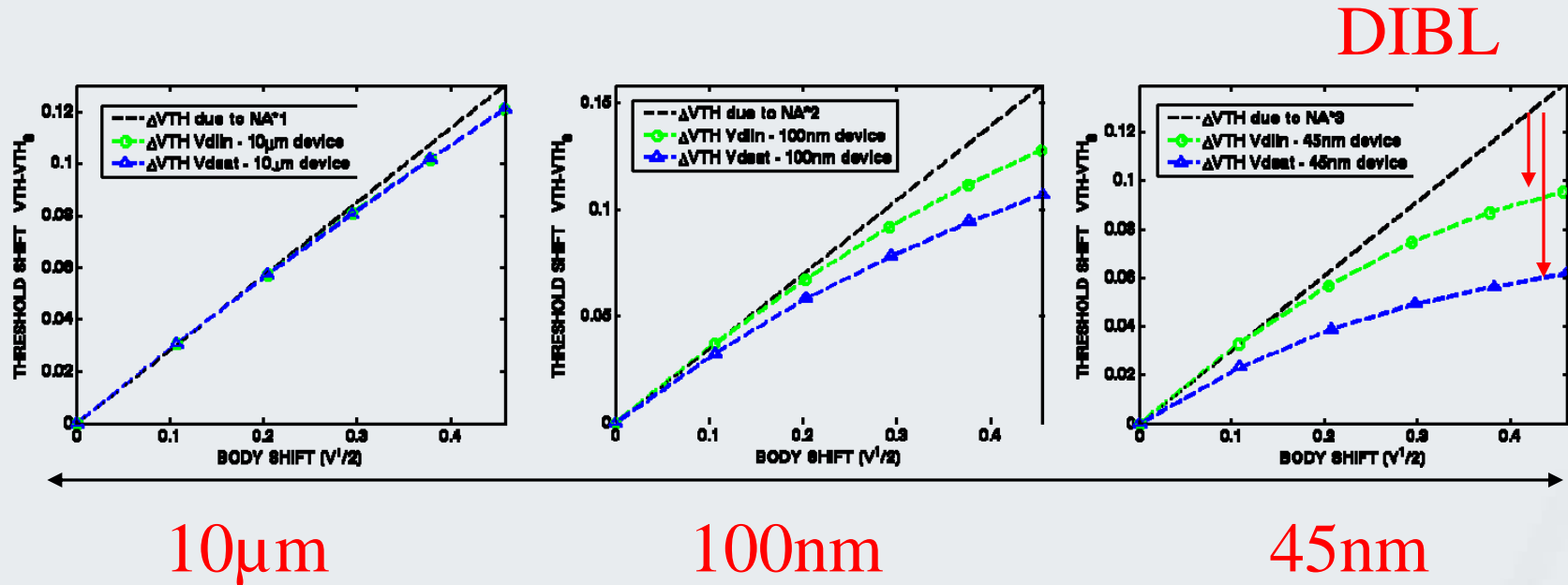


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Body effect for VD polarizations:

- VdLin (VD=50mV) and Vdsat (VD=1.1V)



Lost of control of the channel for high VB:

- enhanced with shortest devices
- high VD polarizations



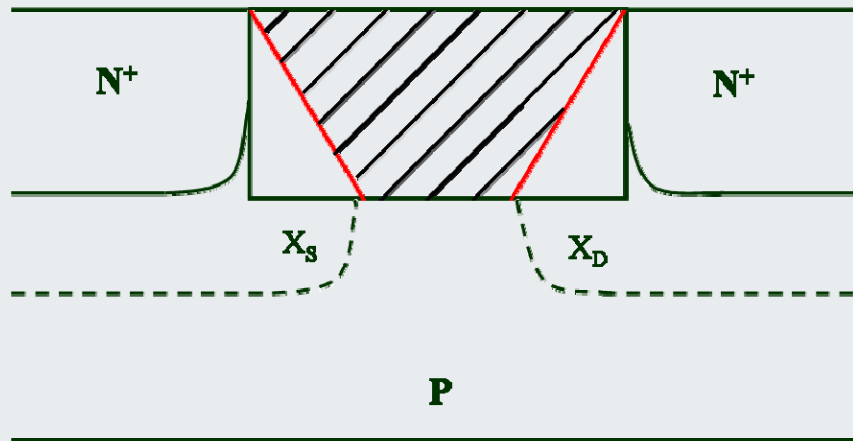


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Charge sharing

- **WU's model (constant sharing model)**



$$X_{S,D} \propto \sqrt{V_{bi} + V_{S,D}}$$



Area where the depleted charges are controlled by the gate.

Geometrical factor reduction from long channel box:

$$F(\psi_s) = 1 - \frac{X_S + X_D}{2 * L} = Cste$$

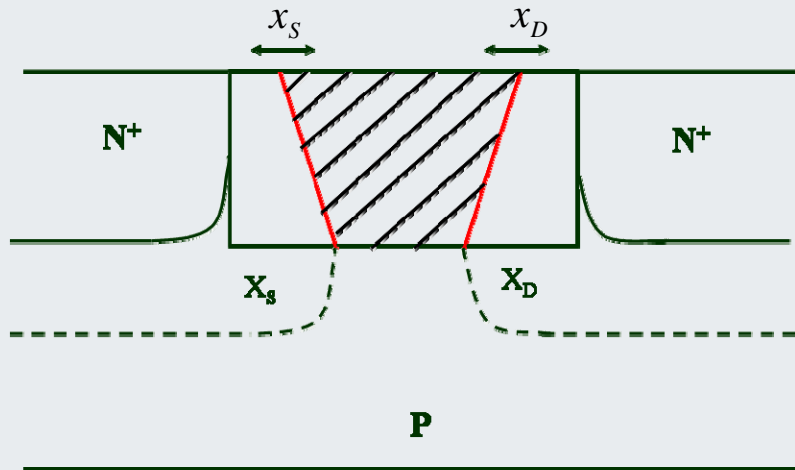


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Charge sharing

- **Dynamic charge sharing model**



$$x_{S,D} \propto \sqrt{V_{bi} + V_{S,D} + \psi_S}$$

Area where the depleted charges are controlled by the gate.

$$F(\psi_S) = 1 - \frac{x_S(\psi_S) + x_D(\psi_S) + X_S + X_D}{2 * L}$$



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Surface Potential Equation

- **Classic equation:**

$$\left(V_G - V_{fb} - \psi_s\right)^2 = \underbrace{\gamma^2 \exp\left(\frac{-2\Phi_F}{\Phi_T}\right) \left(\Phi_T \cdot e^{\frac{\psi_s(y)-V(y)}{\Phi_T}} - \psi_s(y) - \Phi_T \cdot e^{\frac{-V(y)}{\Phi_T}}\right)}_{\text{INVERSION}} + \underbrace{\gamma^2 \psi_s(y)}_{\text{DEPLETION}} + \underbrace{\gamma^2 \Phi_T \left(e^{\frac{-\psi_s(y)}{\Phi_T}} - 1\right)}_{\text{ACCUMULATION}}$$

- **Objective of model:**

Introducing **dynamic charge sharing** in compact model through depletion charge

- **...with dynamic charge sharing:**

$$\left(V_G - V_{fb} - \psi_s\right)^2 = \underbrace{\gamma^2 \exp\left(\frac{-2\Phi_F}{\Phi_T}\right) \left(\Phi_T \cdot e^{\frac{\psi_s(y)-V(y)}{\Phi_T}} - \psi_s(y) - \Phi_T \cdot e^{\frac{-V(y)}{\Phi_T}}\right)}_{\text{INVERSION}} + \underbrace{Q_{dep}^2 F^2}_{\text{MODIFIED DEPLETION}} + \underbrace{\gamma^2 \Phi_T \left(e^{\frac{-\psi_s(y)}{\Phi_T}} - 1\right)}_{\text{ACCUMULATION}}$$





Outline

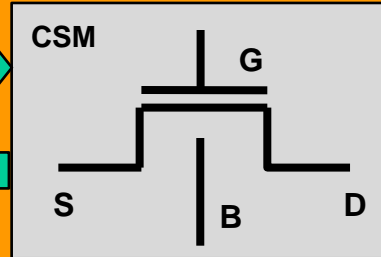
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Surface potential Modeling

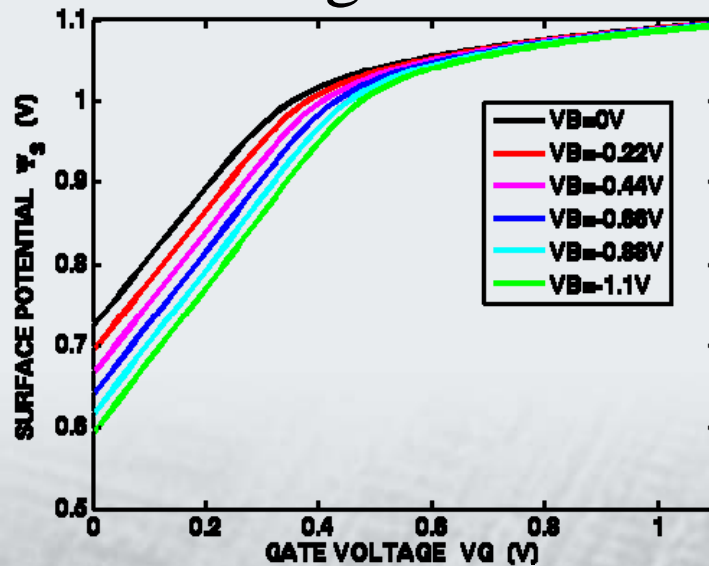
Back bias effects

S.P.E.

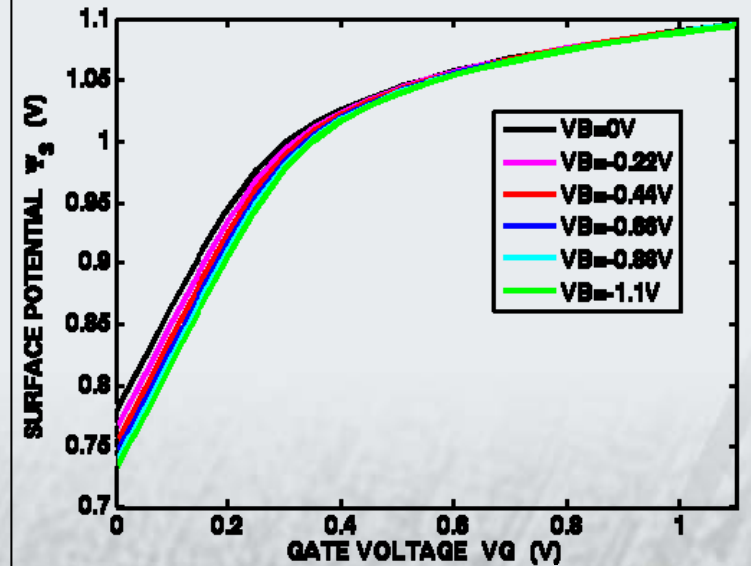
Non-linear
iterative
solver



Long device



Short device





Outline

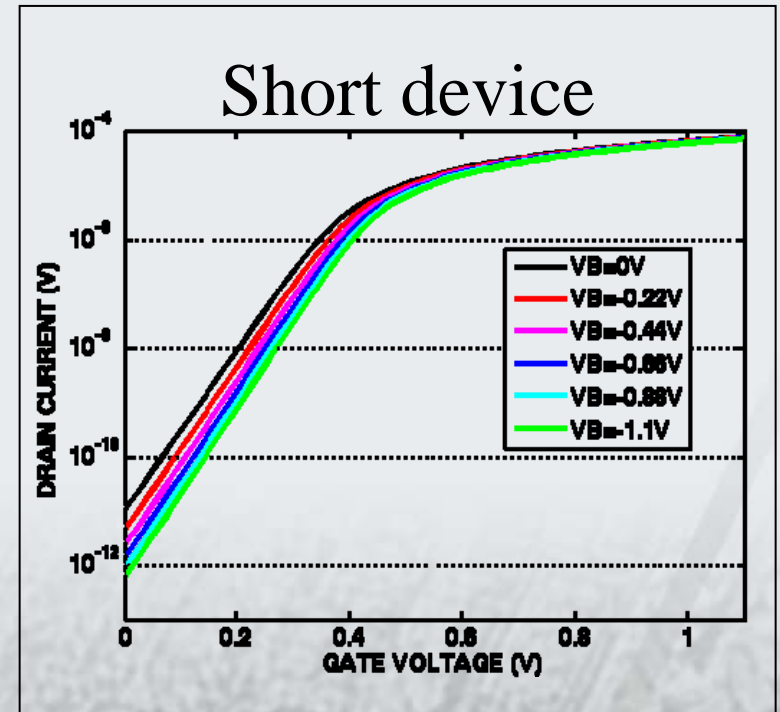
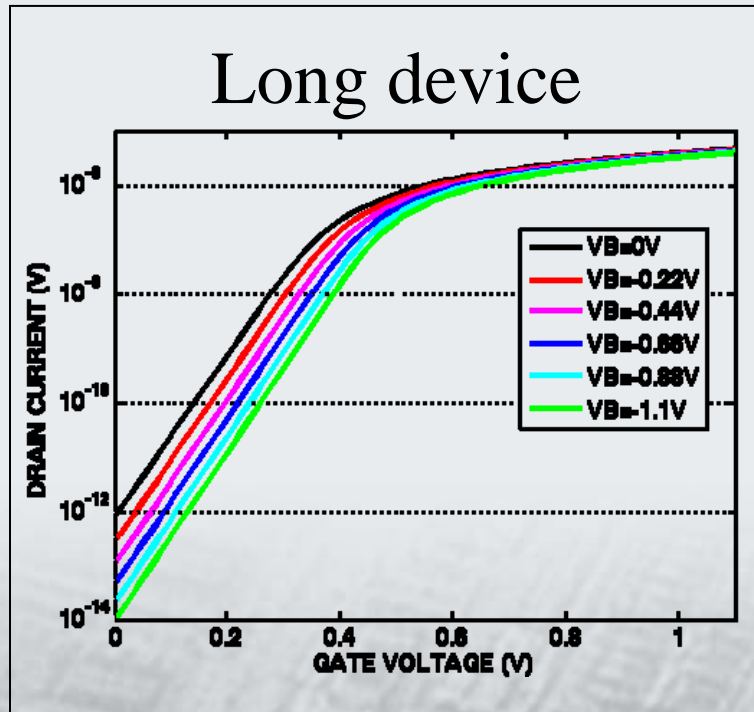
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Id-Vg current Modeling

Back bias effects

- **Brew's approach (Charge Sheet Model):**

- Charges: $q_i(\psi_s) = (Vg - Vfb - \psi_s) \frac{-\gamma\sqrt{\psi_s}}{Q_{iL}} F(\psi_s)$
- Current: $I_d = \int_{\psi_{S0}}^{\psi_{SL}} \mu_n q_i(\psi_s) \cdot d\psi_s + \int_{Q_0} \mu_n d q_i$



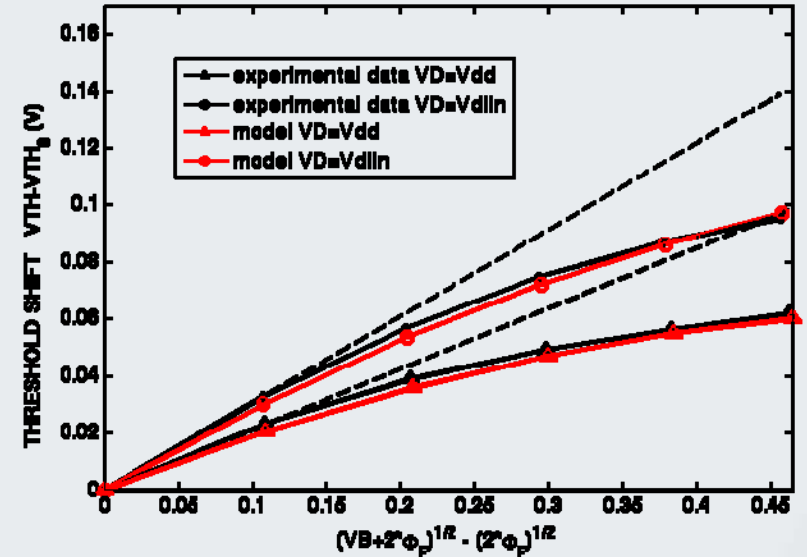
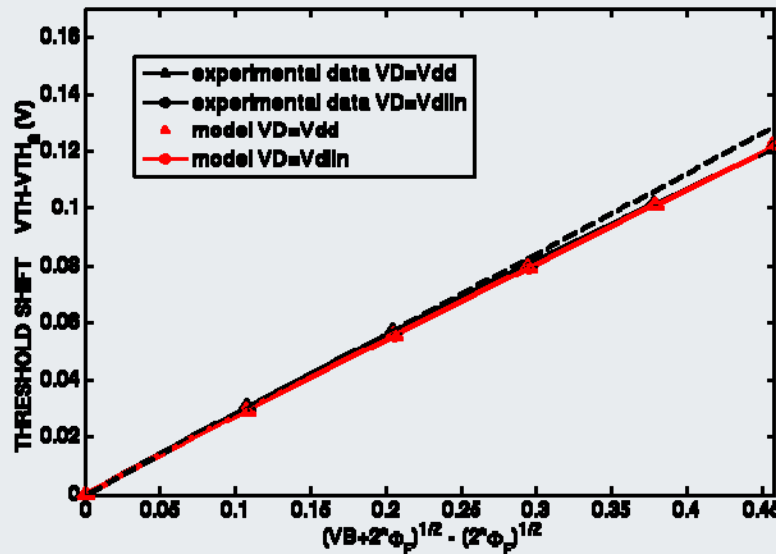


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Charge sharing $V_{th}(V_B)$

- Model validation against **45nm** measurements



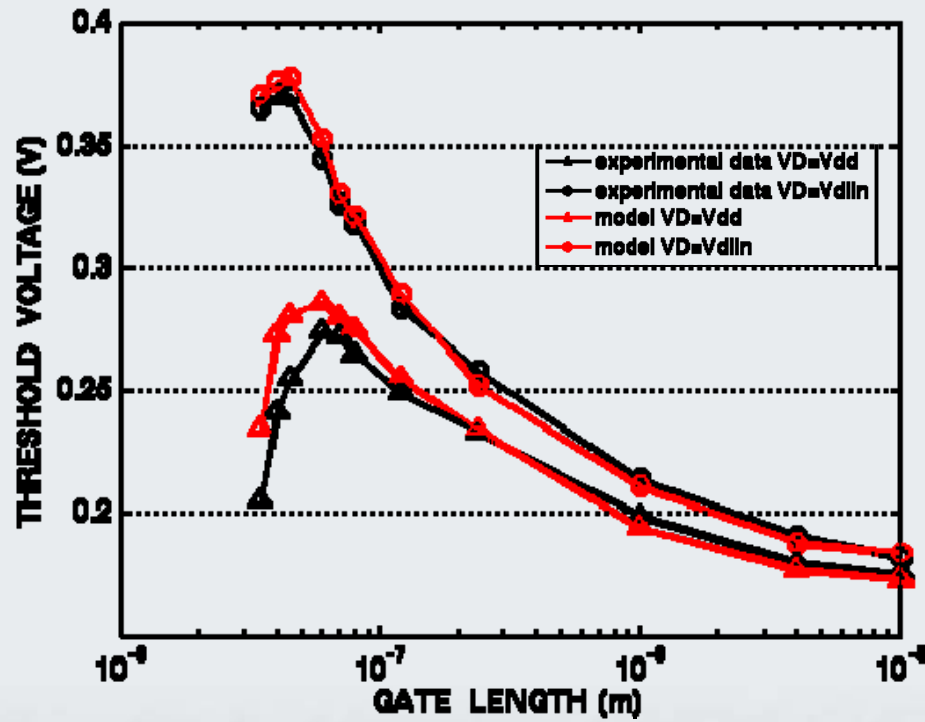


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Charge sharing $V_{th}(L_{gate})$

- Model validation against **45nm** measurements



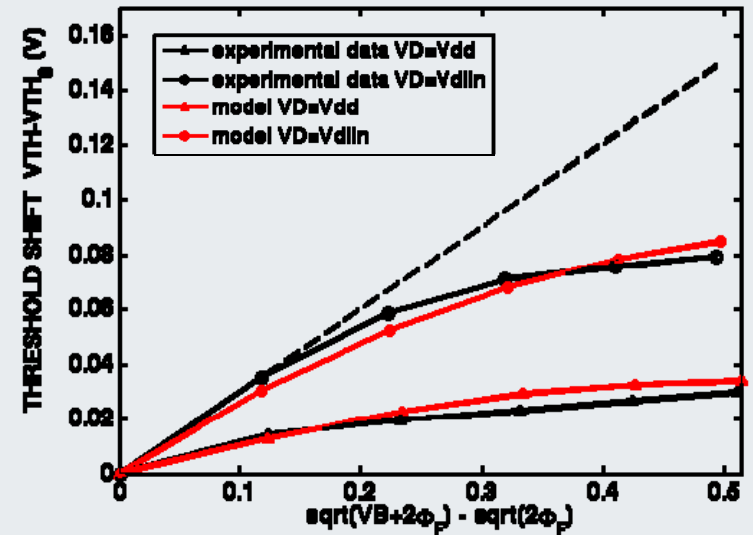
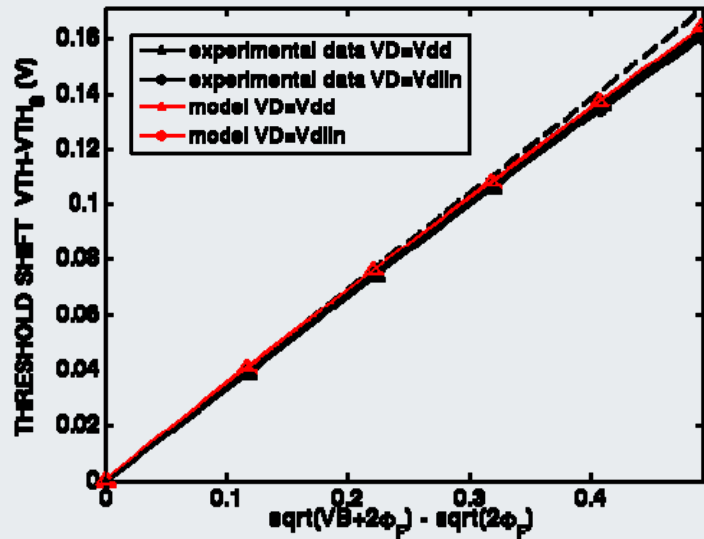


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Charge sharing $V_{th}(V_B)$

- Model validation against **65nm** measurements





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Conclusions / Perspectives

- **Electrical characterization:**
 - $V_{th}(V_b)$ for 45 and 65 nm node
 - Lost of control for tuning the V_{th} for short devices.
- **Compact modeling:**
 - Body effect reproduction requirements for design applications
- **Dynamic charge sharing:**
 - Surface potential dependence of the geometrical coefficient
 - Geometrical coefficient incorporated in Surface Potential Equation
 - Reproduce $V_{th}(V_b)$ 45nm and 65nm data under high and low V_D and various L
- **Evaluating this approach on PSP model (on going):**
 - Requires symmetric linearization (I_d-V_g)





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THANK YOU FOR YOUR ATTENTION !

