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Unified Regional Charge-based MOSFET Model Calibration

Guan Huei See, Siau Ben Chiah, Xing Zhou, Karthik Chandrasekaran, Wangzuo Shangguan^{*}, Shesh Mani Pandey^{*}, Chew Hoe Ang^{*}, Michael Cheng^{*}, Sanford Chu^{*}, and Liang-Choo Hsia^{*}

**School of Electrical & Electronic Engineering, Nanyang Technological University,
Nanyang Avenue, Singapore 639798. exzhou@ntu.edu.sg**

**^{*} Chartered Semiconductor Manufacturing Ltd.
60 Woodlands Industrial Park D, Street 2,
Singapore 738406**

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Outlines

- Modeling methodology**
- Model parameter extraction methodology**
- Model calibration procedure**
- Conclusion**

Modeling Methodology

- MOSFET AC operation is governed by (input) “voltage equation” and (output) “charge equation”.
- ϕ_s and ϕ_p are spatial-dependent variables that link both equations.
- Two implicit eqs. (a, b) are regionally approximated and unified with interpolating functions.
- Single-piece explicit charge models are formulated from unified regional “non-pinned” ϕ_s and ϕ_p models with smooth transitions across regions.
- Combines the best features of surface-potential (for accuracy) and charge-based (for smoothness) approaches.

$$Q_g = C_{ox} (V_{gb} - \phi_{MS} - \phi_s - \phi_p)$$

$$a) V_{gb} - V_{fb} - \phi_s - \phi_p = \text{sgn}(\phi_s) \gamma \sqrt{f_\phi}$$

$$b) V_{gb} - V_{fb} - \phi_s - \phi_p = \text{sgn}(\phi_p) \gamma_p \sqrt{f_{\phi,p}}$$

$$\phi_{acc}, \phi_{pacc}, \phi_{sub}, \phi_{p,sub}, \phi_{str}, \phi_{p,str}$$

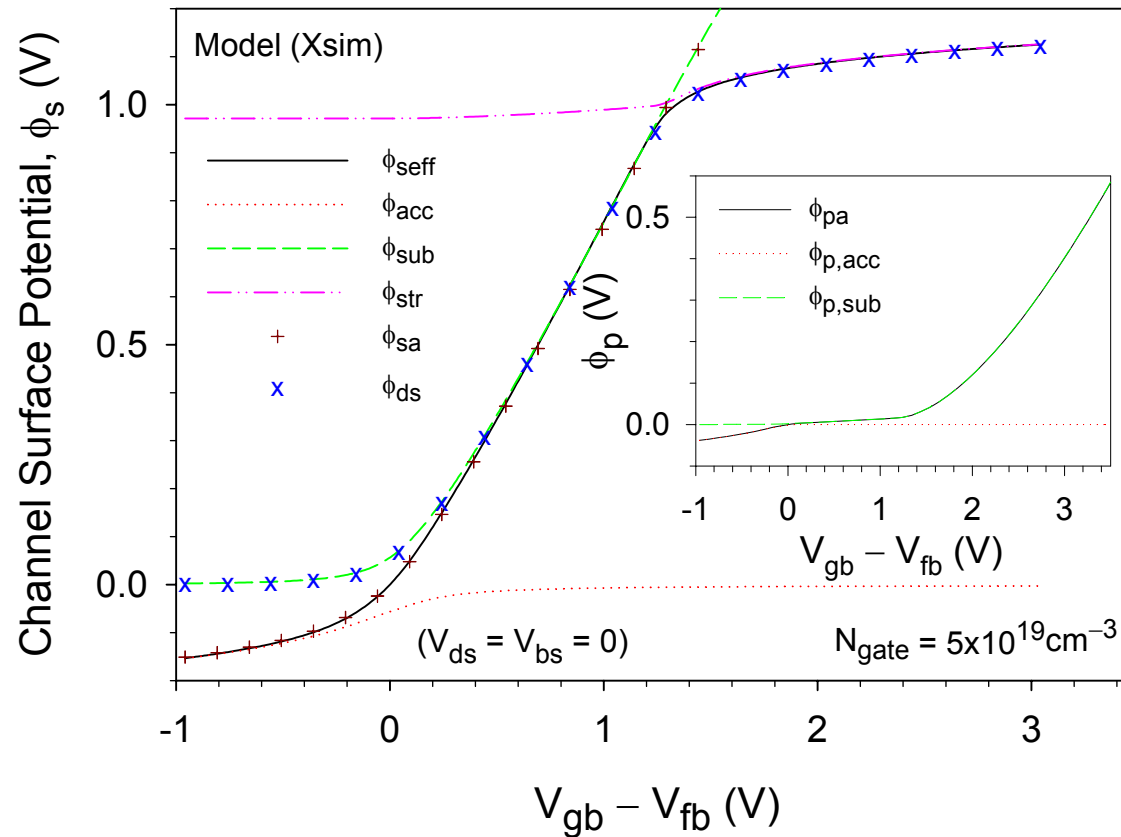
$$\phi_{sa}, \phi_{p,sa}, \phi_{ds}, \phi_{p,ds}$$

$$Q_b = Q_{b0} - C_{ox} D_{b,\Delta}$$

$$Q_{b0} = -C_{ox} (V_{gbr} - \phi_{acc} + V_{gba} - V_{gbf} + \gamma \sqrt{\phi_{ds,s}})$$

Unified Regional Surface Potential

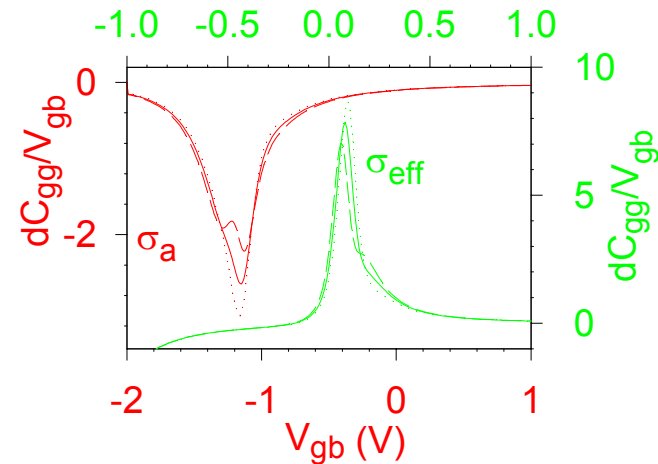
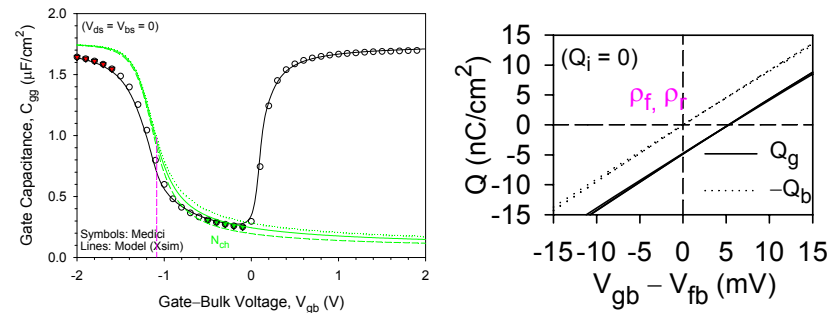
$$\phi_{acc}, \phi_{p,acc}, \phi_{sub}, \phi_{p,sub}, \phi_{str}, \phi_{p,str}, \phi_{sa}, \phi_{p,sa}, \phi_{ds}, \phi_{p,ds}$$



Model Parameter Extraction Methodology

- Characterized into 2 categories:
Physical parameter,
Interpolating parameter.
- Physical parameters: From least-square min RMS between measurement and unified regional models at extreme conditions.
- Interpolating parameters: Ensure charge-neutrality and continuity across two boundary regions (V_{fb} , V_t).
- **One iteration**, **7-step** extraction procedure in a **step-by-step** sequence.
- **One C_{gg}** data. Bias dependency, source/drain partition, non-zero V_{ds} calibration are **not** required.

$$V_{gbf} = \mathcal{G}_f \{x; \sigma_f\}, V_{gbr} = \mathcal{G}_r \{x; \sigma_a\}$$



Model Calibration Procedure

Step-by-step physical parameter extr.

- Step 1: Gate oxide thickness in accumulation region (t_{ox}).

$$Q_{g,acc} = C_{ox} (V_{gb} - \phi_{MS} - \phi_{acc} - \phi_{p,acc})$$

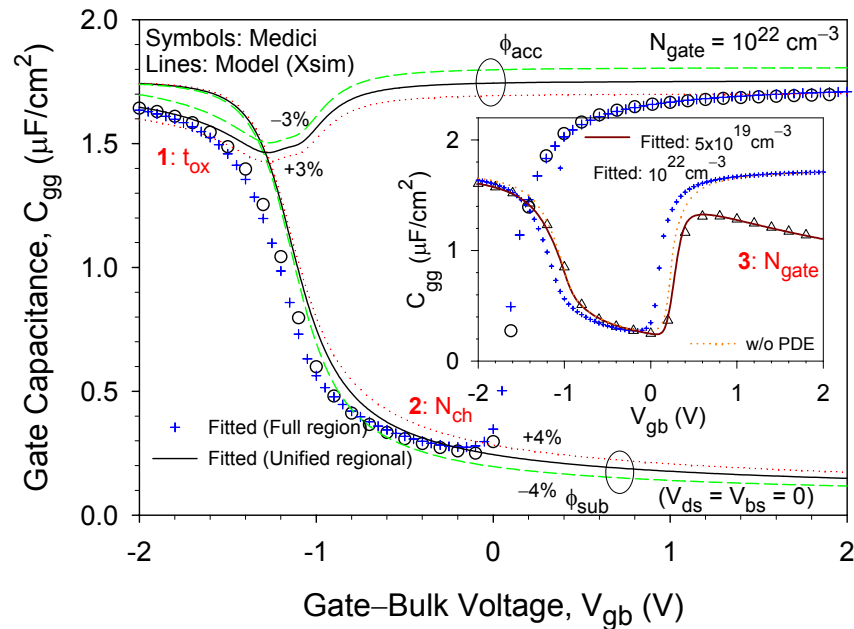
- Step 2: Average channel doping concentration in depletion region (N_{ch}).

$$Q_{g,sub} = C_{ox} (V_{gba} - V_{gbf} + \gamma \sqrt{\phi_{sub}}) - Q_{ox}$$

- Step 3: Average poly-gate doping concentration in strong inversion region (N_{gate}).

$$Q_{g,str} = C_{ox} (V_{gb} - \phi_{MS} - \phi_{str} - \phi_{p,sub})$$

t_{ox}, N_{ch}, N_{gate}



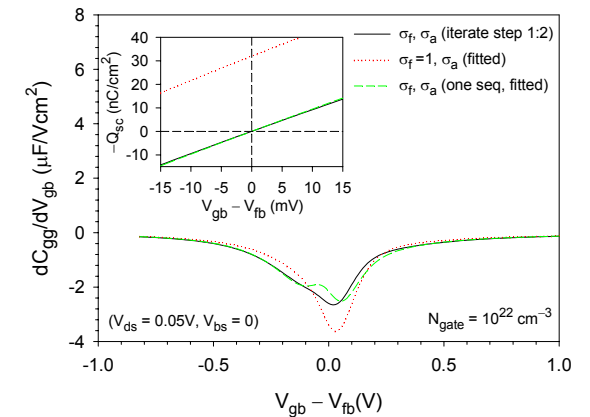
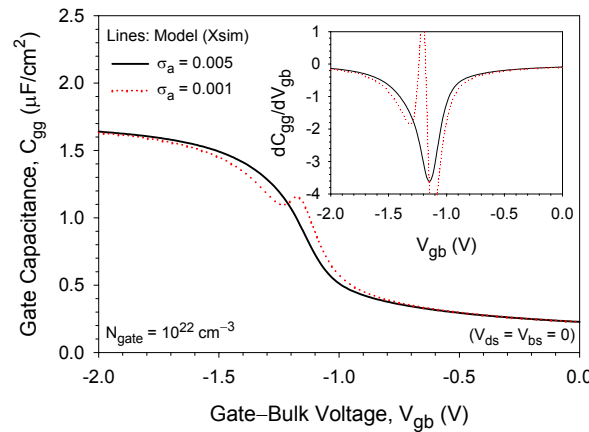
Model Calibration Procedure

Step-by-step interpolating parameter extr.

- Step 4: σ_a and σ_f (region across V_{fb}).

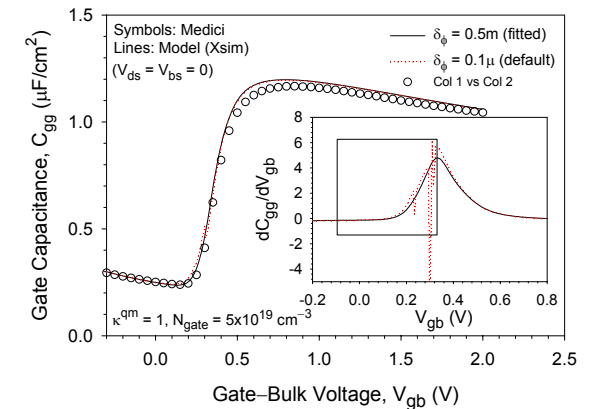
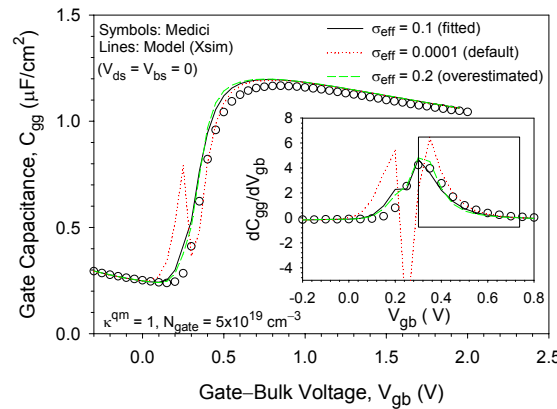
$$Q_{g,sa} = C_{ox} (V_{gb} - \phi_{MS} - \phi_{sa} - \phi_{pa})$$

$$N_{gate} = 10^{22} \text{ cm}^{-3}$$



- Step 5, 6: σ_{eff} and δ_ϕ (region across V_t)

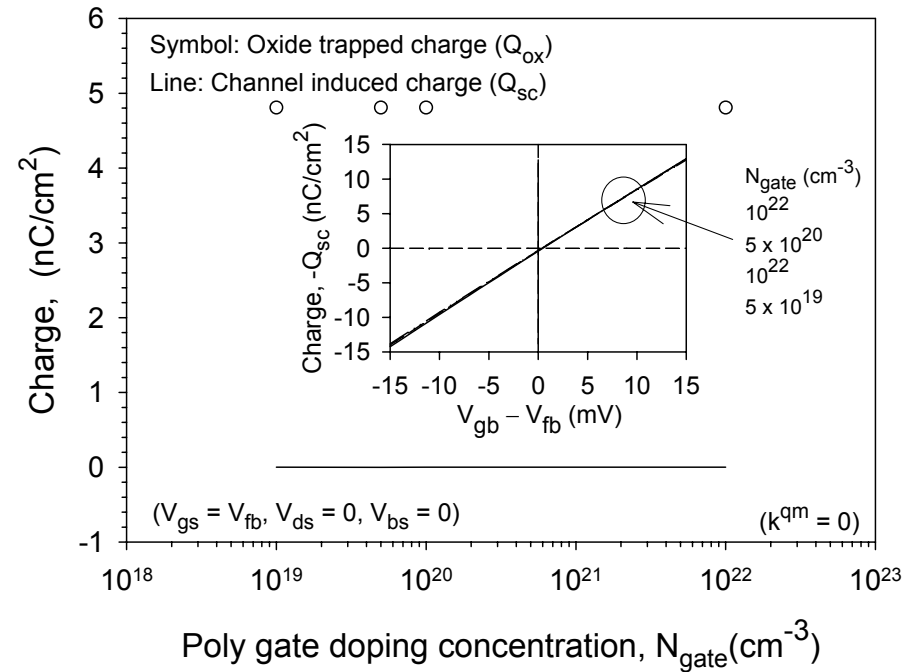
$$Q_{g,ds} = C_{ox} (V_{gb} - \phi_{MS} - \phi_{ds} - \phi_{p,sub})$$



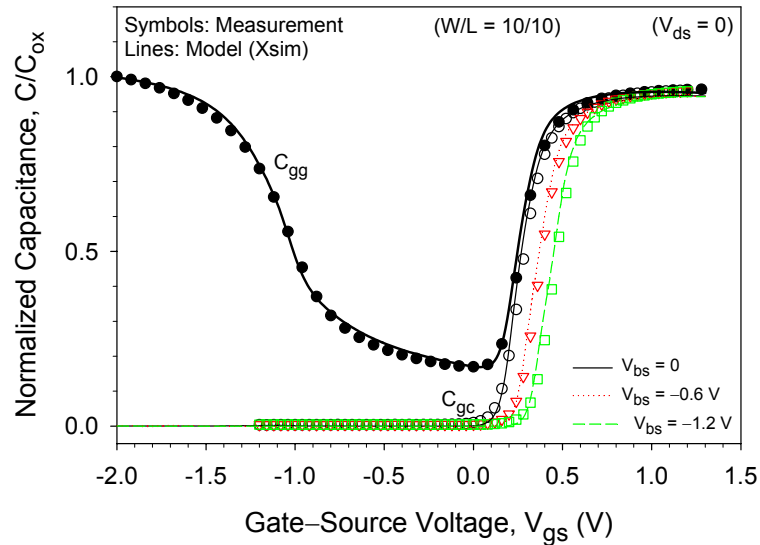
Model Calibration Procedure

- Step 7: ρ_f and ρ_r
(region across V_{fb} – charge neutrality at V_{fb})

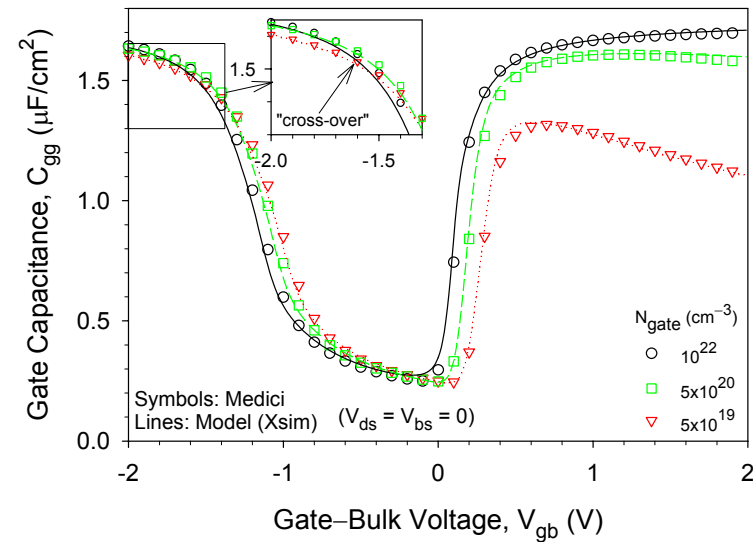
$$Q_{g,acc} = C_{ox} (V_{gb} - \phi_{MS} - \phi_{acc} - \phi_{p,acc})$$



Model Behavior and Prediction

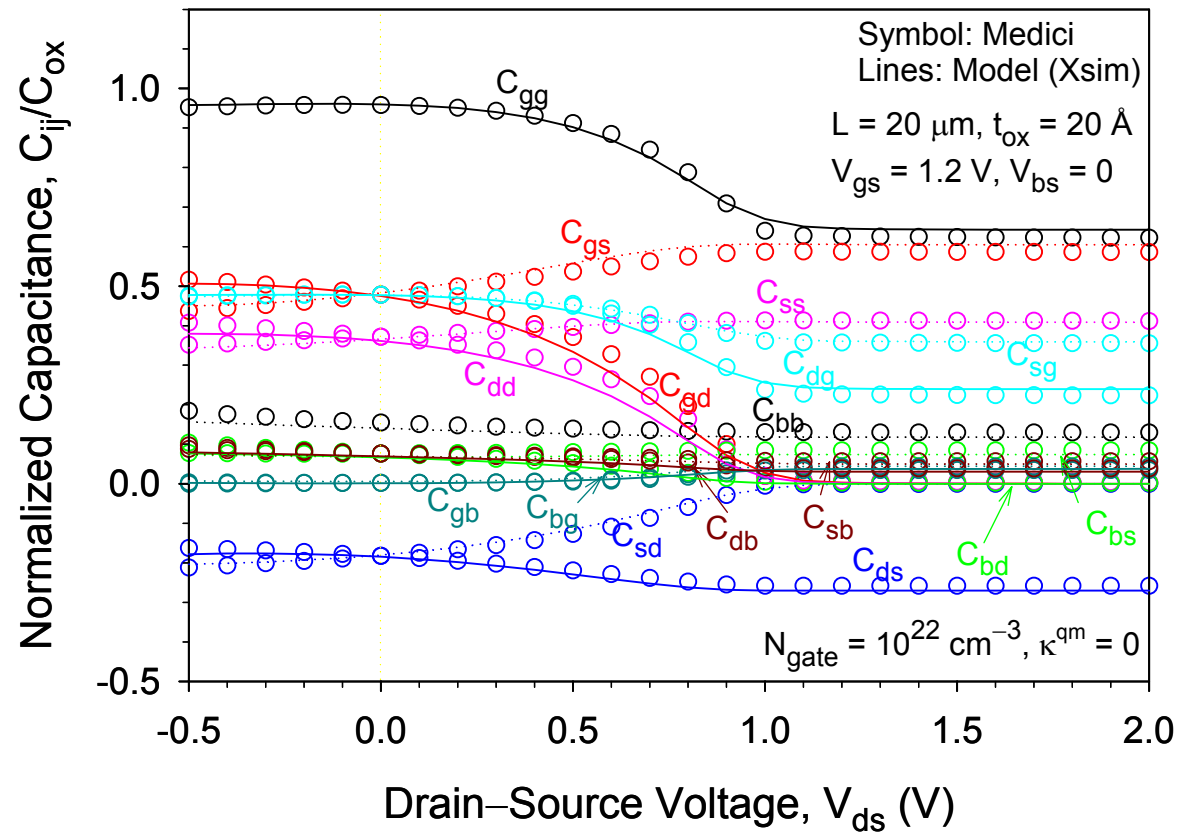


0.11 μm Tech C_{gg} data
(Measurement)
Prediction (V_{bs} dependency)



90 μm Tech C_{gg} data
(Numerical simulation)
Prediction (N_{gate} dependency)

Model Behavior and Prediction



Transcapacitances (Symmetry)

Conclusions

❑ Modeling Methodology

- Single-piece explicit charge models are formulated from **unified regional “non-pinned” ϕ_s and ϕ_p** model with smooth transitions across regions.

❑ Model Parameter Extraction Methodology

- Only one C_{gg} data is required. No further calibration is needed for source–drain partition, bias dependency and non-zero V_{ds} characteristics.
- 3 physical and 6 interpolating parameters are extracted based on ***one-iteration, 7-step*** extraction procedure (step-by-step).

❑ Enhancement

- The charge modeling approach has been extended to non-conventional bulk-silicon MOSFET. (multilayer, strain-Si MOSFETs).