Unified Regional Charge-based Versus Surface-potential-based Compact Modeling Approaches

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Presentation Outline

- **Charge modeling:** Pao–Sah surface-potential solutions
- **Unified regional approach**
  - Piecewise/regional and non-pinned surface potential
  - Unified regional charge model
  - Charge-based bias-scalable transcapacitances and symmetry
  - Poly-accumulation/depletion/inversion effects
  - Coupled quantum-mechanical effect with PAE/PDE
  - Extension to strained-Si MOSFET charge modeling
  - One/two-iteration AC model parameter extraction
- **DC model calibration and prediction**
  - Minimum data for model calibration
  - One-iteration parameter extraction
- **Summary and conclusions**

Comparison of Modeling Approaches

Surface-potential (ϕ_s) based

Iterative **MM11** **HiSIM**

+

Explicit **SP** = **PSP**

(Accurate physics built-in for all regions; inherent requirement of high ϕ_s accuracy)

(Inversion)-charge (Q_i) based

EKV **ACM** **BSIM5**

(Not as accurate but less demanding on high ϕ_s accuracy; still need ϕ_s solutions in extrinsic and accumulation)

Threshold-voltage (V_t) based

(Pinned surface potential)

BSIM3,4 **MM9**

(Less physical in strong inversion)

Unified, single-piece, explicit ***regional*** charge-based model with ***non-pinned*** surface potential

Xsim: unique features — combining "accurate" physics in *surface potential* solutions with unified "smooth" *regional charges* without losing the "process-dependent" *threshold voltage* concept

- Do not solve at $V_{gb} = V_{fb}$, but two regional pieces unified to form a *single-piece* with C_∞ continuity (no 'if' conditionals anywhere)
- Do not require high accuracy in ϕ_s since charges ($V_{ds} = 0$) do not depend on $\phi_{s0} - \phi_{sL}$
- Consistent with conventional formulations
- Easy extension to include higher-order effects (QM, poly-doping, strained-Si, 2D SCEs, …)

The Complete Potential/Charge Balance (“Pao–Sah”)

$$F \equiv V_{gb} - V_{fb} - \phi_s = \mathrm{sgn}(\phi_s)\,\gamma\sqrt{v_{th}\left[\exp\left(-\frac{\phi_s}{v_{th}}\right) - 1 + \frac{\phi_s}{v_{th}}\right] + v_{th}\exp\left(-\frac{V_{cb}+2\phi_F}{v_{th}}\right)\left[\exp\left(\frac{\phi_s}{v_{th}}\right) - 1 - \frac{\phi_s}{v_{th}}\exp\left(\frac{V_{cb}}{v_{th}}\right)\right]}$$

$$K \begin{cases} = e^{V_{cb}/v_{th}} & \text{Original Pao–Sah: negative } F^2 \text{ for small positive } \phi_s \text{ (when } V_{cb} > 0) \\ = 0 & \text{Modified Pao–Sah: negative } F^2 \text{ for small negative } \phi_s \text{ (when } V_{cb} > 0) \\ = 1 & \text{Modified Pao–Sah: no negative } F^2 \text{ (used in iterative/explicit solutions)} \end{cases}$$

$K \equiv e^{V_{cb}/v_{th}}$ — **1966 Pao–Sah**

$$V_{gb} - V_{fb} - \phi_s = \mathrm{sgn}(\phi_s)\,\gamma\sqrt{f_\phi} = \pm\gamma\sqrt{v_{th}\left[\exp\left(-\frac{\phi_s}{v_{th}}\right) - 1\right] + \phi_s - \phi_s\exp\left(-\frac{2\phi_F}{v_{th}}\right) + v_{th}\exp\left(-\frac{V_{cb}+2\phi_F}{v_{th}}\right)\left[\exp\left(\frac{\phi_s}{v_{th}}\right) - 1\right]}$$

$$\overbrace{(Q_g + Q_{ox})/C_{ox}}\;\; \overbrace{-Q_{sc}/C_{ox}} = \overbrace{-Q_b/C_{ox} = -(Q_{acc} + Q_{sub} + Q_{str})/C_{ox}}^{(p)\qquad (N_A - N_D)} + \overbrace{-Q_i/C_{ox} = -(Q_s + Q_d)/C_{ox}}^{(n)}$$

$$Q_g = -(Q_b + Q_i + Q_{ox})$$

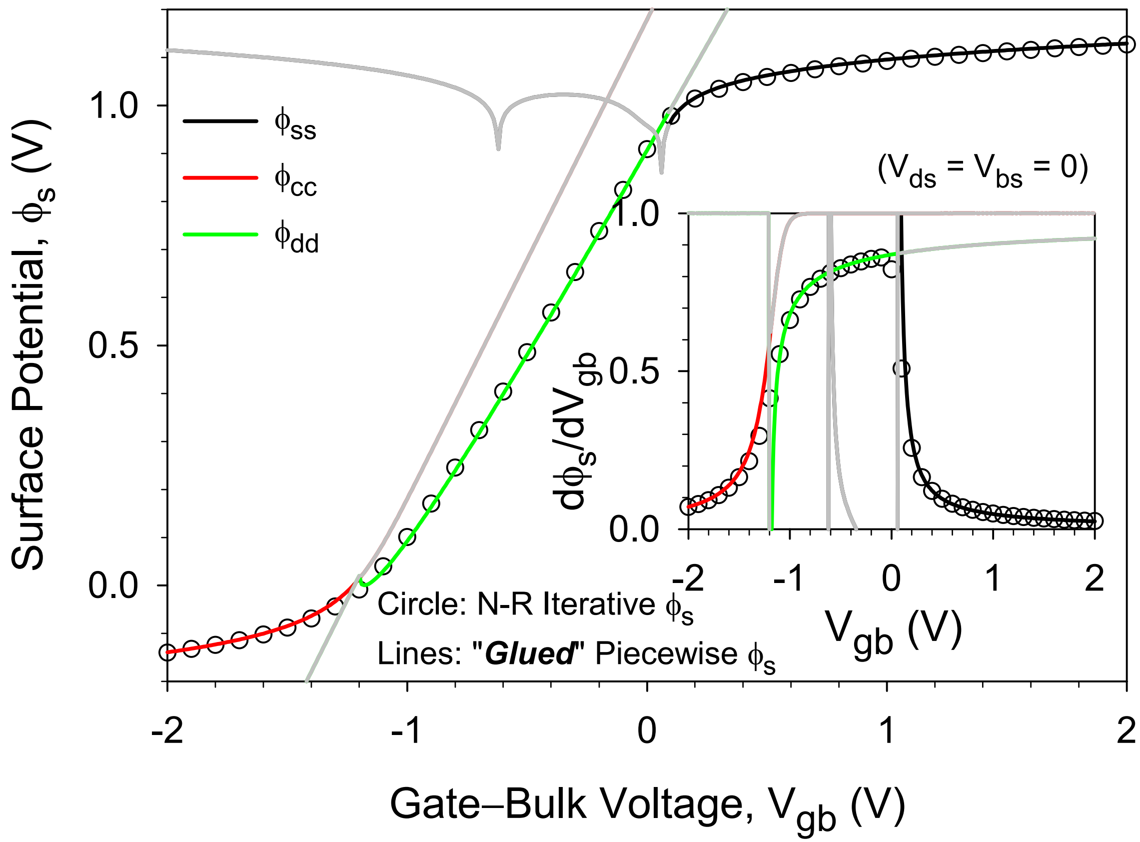
Charge balance ($Q_g + Q_{ox}$)

Unified regional (Q_b): one-piece (Q_{acc}, Q_{sub}); smoothing (Q_{sub}, Q_{str})

Ward–Dutton partition (Q_s, Q_d)

- $V_{ds} = 0$: same as source-end ϕ_{s0}
- $V_{ds} \neq 0$: built into V_{deff} (R_{sd}, V_{Aeff})

"Glued" Piecewise Regional ϕ_s Solutions



- Simple piecewise regional ϕ_s solutions:

$$\phi_{ss} = \phi_B + \Delta$$

$$\phi_{cc} = V_{gb} - V_{fb} + 2v_{th}\mathcal{L}\{w\}$$

$$\phi_{dd} = \left(-\frac{\gamma}{2} + \sqrt{\frac{\gamma^2}{4} + V_{gb} - V_{fb}}\right)^2$$

- When "**glued**" together, *glitches* at flat-band (V_{fb}, ϕ_s = 0) and threshold (V_t, $\phi_s = 2\phi_F$) conditions

- Even with careful math for explicit solution, *ripple* may occur when solution pieces are "glued"

Piecewise and Unified Regional Pao–Sah Solutions

$$V_{gb}-V_{fb}-\phi_B=\gamma\sqrt{\phi_B+v_{th}+v_{th}\exp\left(-\frac{V_{cb}+2\phi_F}{v_{th}}\right)\exp\left(\frac{\phi_s}{v_{th}}\right)}$$

$$\longrightarrow \phi_B=2\phi_F+V_{cb}\longrightarrow \phi_{ss}=\phi_B+\Delta\longrightarrow \phi_{str}$$

$$\Delta=v_{th}\ln\left\{\frac{1}{v_{th}}\left[\left(\frac{V_{gb}-V_{fb}-\phi_{ss}^*}{\gamma}\right)^2-(\phi_{s0}+V_{cb})\right]+1\right\}$$

$$\phi_{ss}^*=\phi_{s0}+V_{cb}+\frac{\phi_{dd}-(\phi_{s0}+V_{cb})}{\sqrt{1+\left[\frac{\phi_{dd}-(\phi_{s0}+V_{cb})}{4v_{th}}\right]^2}}$$

$$\phi_{seff}=\phi_{acc}+\phi_{ds}$$

$$V_{gb}-V_{fb}-\phi_s=\gamma\sqrt{\phi_s}$$

$$\downarrow$$

$$\phi_{dd}=\left(-\frac{\gamma}{2}+\sqrt{\frac{\gamma^2}{4}+V_{gb}-V_{fb}}\right)^2$$

$$V_{gb}-V_{fb}\rightarrow V_{gbf} \longrightarrow \phi_{sub}$$

$$\phi_{ds}=\vartheta_{eff}\left\{\phi_{sub},\phi_{str};\delta_\phi\right\}$$

$$\Delta=v_{th}\ln\left\{b_{eff}\right\}$$

$$b_{eff}=\frac{1}{v_{th}}\vartheta_f\left\{\left(\frac{V_{ga}}{\gamma}\right)^2-(\phi_{s0}+V_{cb});\sigma_{eff}\right\}+1$$

$$V_{ga}=\vartheta_f\left\{V_{gb}-V_{fb}-\phi_{str}^*;\sigma_{vga}\right\}$$

$$V_{gb}-V_{fb}-\phi_s=-\gamma\sqrt{v_{th}\exp\left(-\frac{\phi_s}{v_{th}}\right)}$$

$$\downarrow$$

$$\phi_{cc}=V_{gb}-V_{fb}+2v_{th}\mathcal{L}\{w\}$$

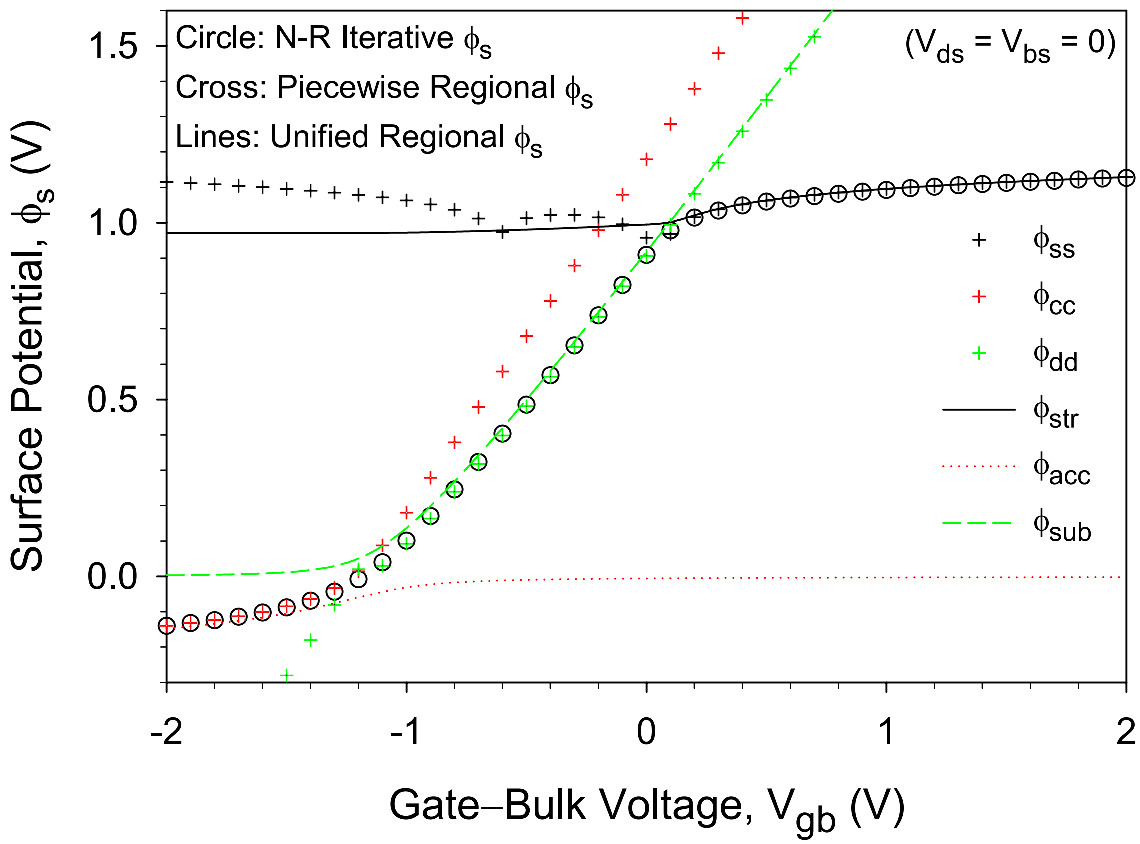
$$V_{gb}-V_{fb}\rightarrow V_{gbr} \longrightarrow \phi_{acc}$$

$$\phi_{sa}=\phi_{acc}+\phi_{sub}$$

$$\vartheta_f\{x;\sigma\}\equiv 0.5\left(x+\sqrt{x^2+4\sigma}\right)$$

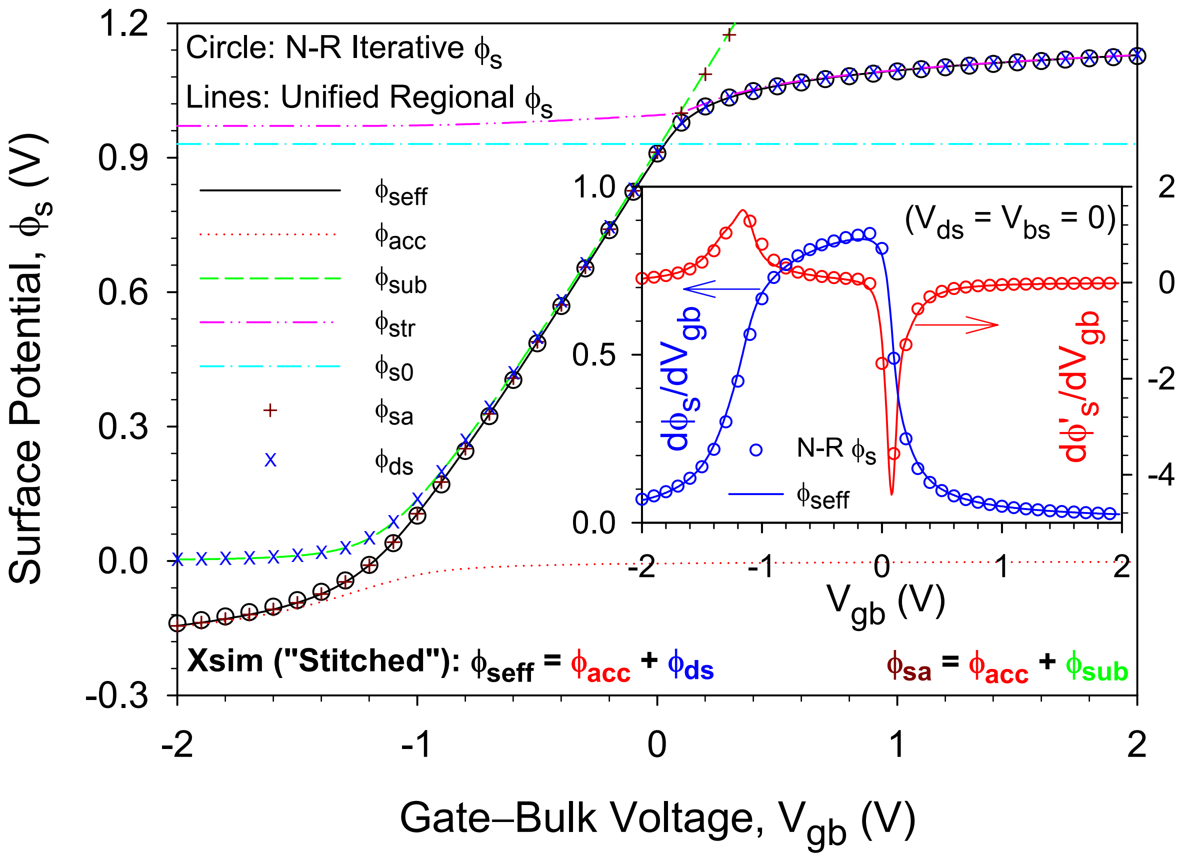
$$\vartheta_r\{x;\sigma\}\equiv -0.5\left(-x+\sqrt{x^2+4\sigma}\right)$$

Piecewise and Unified Regional ϕ_s Solutions



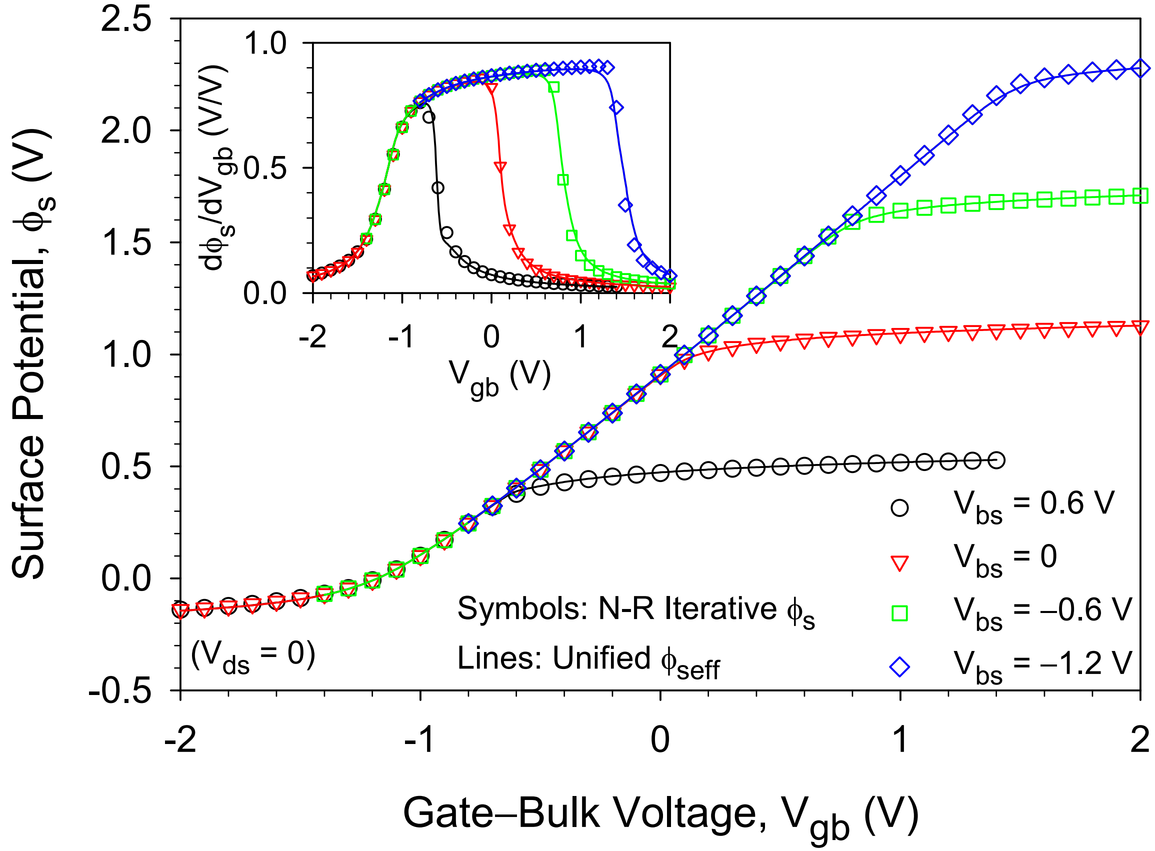
- Piecewise regional solutions are derived physically
- Unified regional solutions approach the respective physical solutions asymptotically
- Transition regions are “controlled” by the smoothing parameters, whose values do not influence asymptotic solutions

Unified ϕ_s Solutions and Continuity



- ϕ_s at $V_{gb} = V_{fb}$ is not solved exactly, but two pieces "**stitched**" to form a single-piece (ϕ_{seff}) seamlessly
- ϕ_{seff} solution can be arbitrarily close to V_{fb} without any 'if' conditionals, with C_∞ continuity
- ϕ_{acc} and ϕ_{sub} are independent of V_{ds}; ϕ_{str} evaluated at the source/drain ends, keeping symmetry

Single-piece Unified ϕ_{seff} and ϕ'_{seff} in *All* Regions



- Single-piece ϕ_{seff} in all bias regions, including forward bulk bias
- Not directly used in charge formulations; only the regional solutions are used in the *unified regional charge model*

Unified Charge Model with Non-pinned Surface Potential

$$Q_i(y) = -C_{ox}\left[V_{gb} - V_{fb} - \psi_s(y)\right] - Q_b(y)$$ [Ward & Dutton]

$$Q_i = Q_s + Q_d$$

Piecewise regional: → **Unified regional (pinned, no 'Δ'):** → **Non-pinned:**

$$Q_s = -C_{ox}\left(\frac{V_{gs} - V_t}{2} - \frac{A_b}{6}V_{ds} + A_s\right)$$

$$Q_d = -C_{ox}\left(\frac{V_{gs} - V_t}{2} - \frac{A_b}{3}V_{ds} + A_d\right)$$

$$A_s = \mathcal{A}(1 - \mathcal{B})$$

$$A_d = \mathcal{A}\mathcal{B}$$

$$D_b = (A_b - 1)V_{ds}\mathcal{D}$$

$$\mathcal{A} = \frac{A_b^2 V_{ds}^2}{12(V_{gs} - V_t - 0.5A_b V_{ds})}$$

$$\mathcal{B} = \frac{5(V_{gs} - V_t) - 2A_b V_{ds}}{10(V_{gs} - V_t - 0.5A_b V_{ds})}$$

$$\mathcal{D} = \frac{3(V_{gs} - V_t) - 2A_b V_{ds}}{6(V_{gs} - V_t - 0.5A_b V_{ds})}$$

$$Q_{s,\Delta} = -C_{ox}\left(\frac{V_{gt,\phi}}{2} - \frac{A_{b,\Delta}}{6}V_{deff,\Delta} + A_{s,\Delta}\right)$$

$$Q_{d,\Delta} = -C_{ox}\left(\frac{V_{gt,\phi}}{2} - \frac{A_{b,\Delta}}{3}V_{deff,\Delta} + A_{d,\Delta}\right)$$

$$\mathcal{A}_{eff,\Delta} = \frac{A_{b,\Delta}^2 V_{deff,\Delta}^2}{12\left(V_{geff,\Delta} - \tfrac{1}{2}A_{b,\Delta}V_{deff,\Delta}\right)}$$

$$\mathcal{B}_{eff,\Delta} = \frac{5V_{geff,\Delta} - 2A_{b,\Delta}V_{deff,\Delta}}{10\left(V_{geff,\Delta} - \tfrac{1}{2}A_{b,\Delta}V_{deff,\Delta}\right)}$$

(Derived from 'pinned' I_{ds})

$$V_{t,\Delta} = V_t + A_b\Delta_{eff,s}$$

$$V_{deff,\Delta} = V_{deff} + \Delta_{ds}$$

$$V_{geff,\Delta} = V_{geff}(V_{t,\phi})$$

$$A_{b,\Delta} = 1 + \frac{\gamma}{2\sqrt{\phi_{s0} + \Delta_{eff,s} - V_{bs}}}$$

$$V_{t,\phi} = V_{FB} + \phi_{str,s} + \gamma\sqrt{\phi_{str,s}} + V_{bs}$$

$$V_{gt,\phi} = nv_{th}\ln\left(1 + e^{(V_{gs} - V_{t,\phi})/(nv_{th})}\right)$$

$$A_{s,\Delta} = \mathcal{A}_{eff,\Delta}\left(1 - \mathcal{B}_{eff,\Delta}\right) \quad A_{d,\Delta} = \mathcal{A}_{eff,\Delta}\mathcal{B}_{eff,\Delta} \quad D_{b,\Delta} = (A_{b,\Delta} - 1)V_{deff,\Delta}\mathcal{D}_{eff,\Delta}$$

Unified Regional Bulk-Charge Modeling

$$-\left(V_{gb}-V_{fb}-\phi_s\right)=-\left(Q_g+Q_{ox}\right)\approx -Q_g \quad = \quad Q_{sc} \quad = \quad Q_b \approx Q_b + Q_i = -\operatorname{sgn}\left(\phi_s\right)C_{ox}\sqrt{f_\phi}$$

$$V_{gb}-V_{fb}\equiv V_{gba}\left(\sigma_a\right)+V_{gbr}\left(\sigma_a\right)$$

$$\phi_{sa}=\phi_{acc}+\phi_{sub}$$

$$V_{gbf}=\vartheta_f\left\{V_{gb}-V_{fb};\sigma_f\right\}$$

$$V_{gbr}=\vartheta_r\left\{V_{gb}-V_{fb};\sigma_a\right\}$$

$$V_{gba}=\vartheta_f\left\{V_{gb}-V_{fb};\sigma_a\right\}$$

$$\begin{aligned}
Q_{b,sa} &= Q_{sc} = -C_{ox}\left(V_{gb}-V_{fb}-\phi_{sa}\right)\\
&= -C_{ox}\left[\left(V_{gba}+V_{gbr}\right)-\left(\phi_{acc}+\phi_{sub}\right)\right]\\
&= -C_{ox}\left[\left(V_{gbr}-\phi_{acc}\right)+\left(V_{gba}-\phi_{sub}\right)+\left(V_{gbf}-V_{gbf}\right)\right]\\
&= -C_{ox}\left[\left(V_{gbr}-\phi_{acc}\right)+\left(V_{gba}-V_{gbf}\right)+\left(V_{gbf}-\phi_{sub}\right)\right]\\
&= Q_{b,acc}+Q_{b,sub}
\end{aligned}$$

$$Q^*_{b,sub}\equiv -C_{ox}\left(V_{gbf}-\phi_{sub}\right)=-\gamma C_{ox}\sqrt{\phi_{sub}}$$

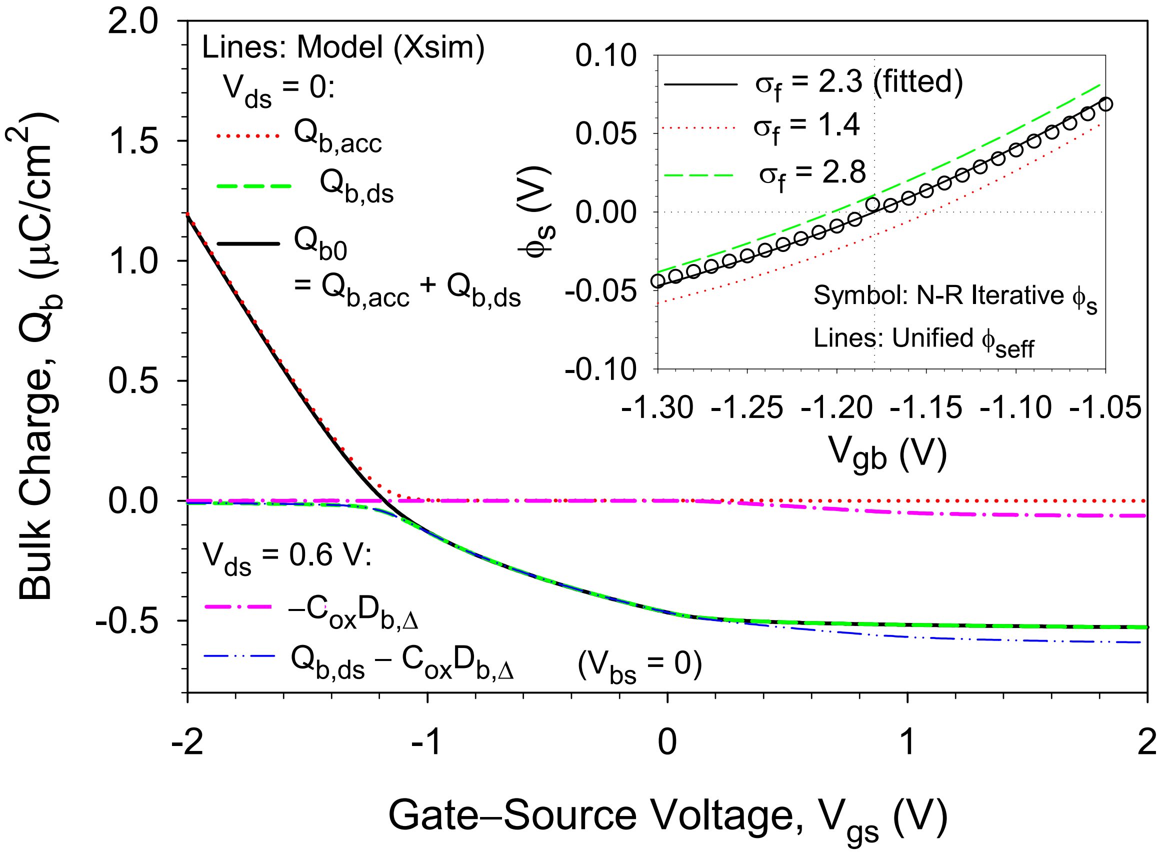
$$Q_{b,acc}\equiv -C_{ox}\left(V_{gbr}-\phi_{acc}\right)$$

$$Q_{b,sub}\equiv -C_{ox}\left(V_{gba}-V_{gbf}+\gamma\sqrt{\phi_{sub}}\right) \longrightarrow Q_{b,ds}=-C_{ox}\left(V_{gba}-V_{gbf}+\gamma\sqrt{\phi_{ds,s}}\right)$$

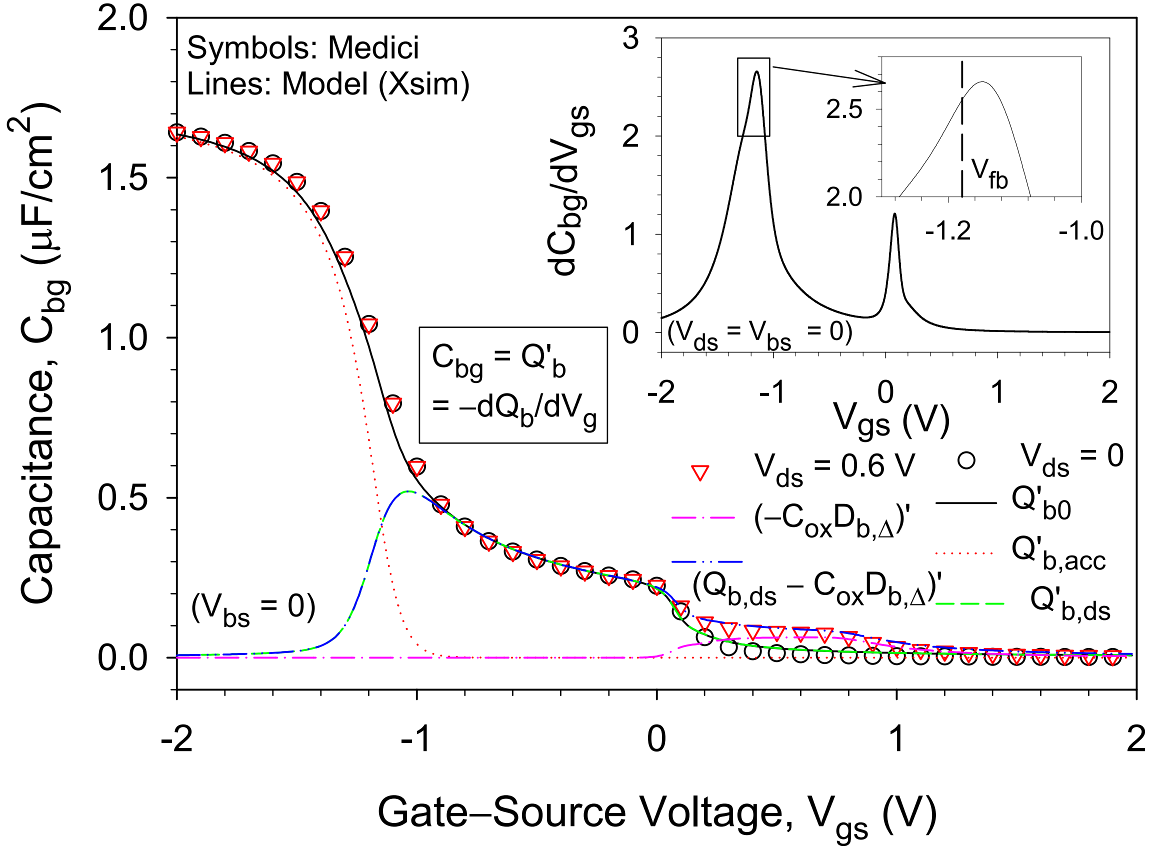
$$Q_{b0}=Q_{b,acc}+Q_{b,ds}$$

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

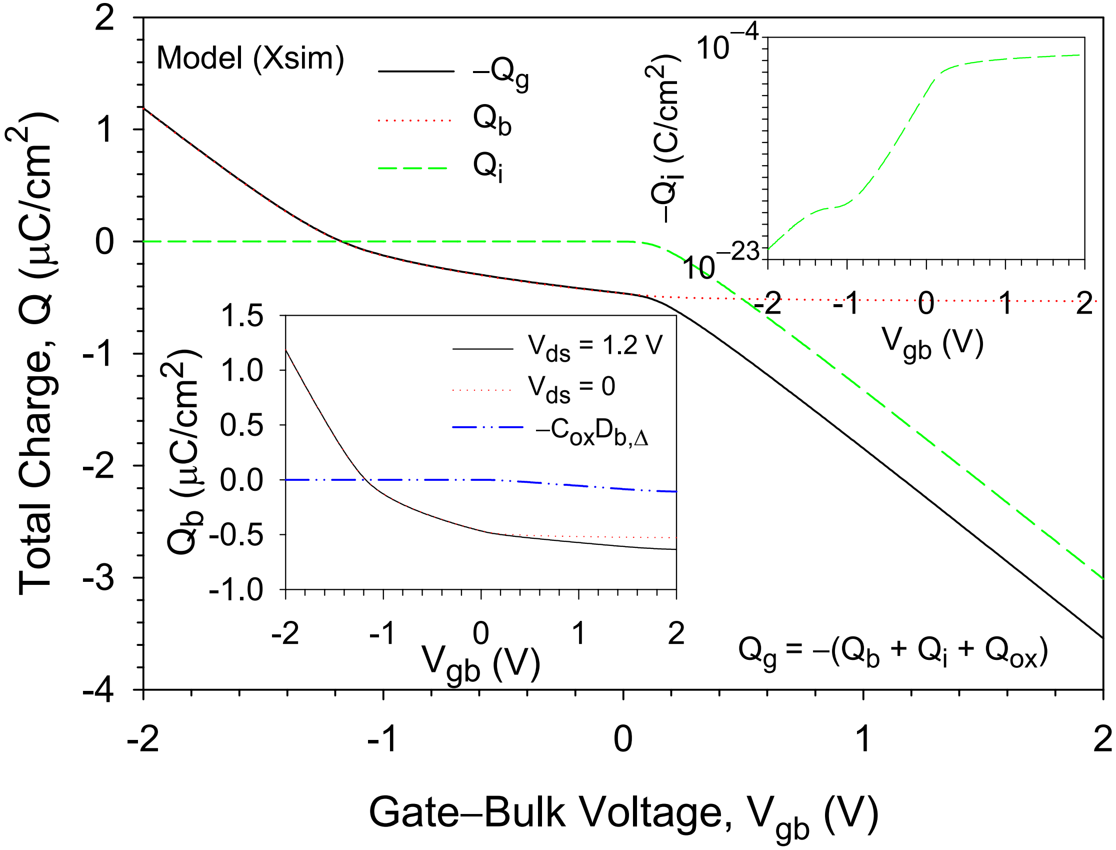
Unified Regional Bulk Charge and Charge Neutrality



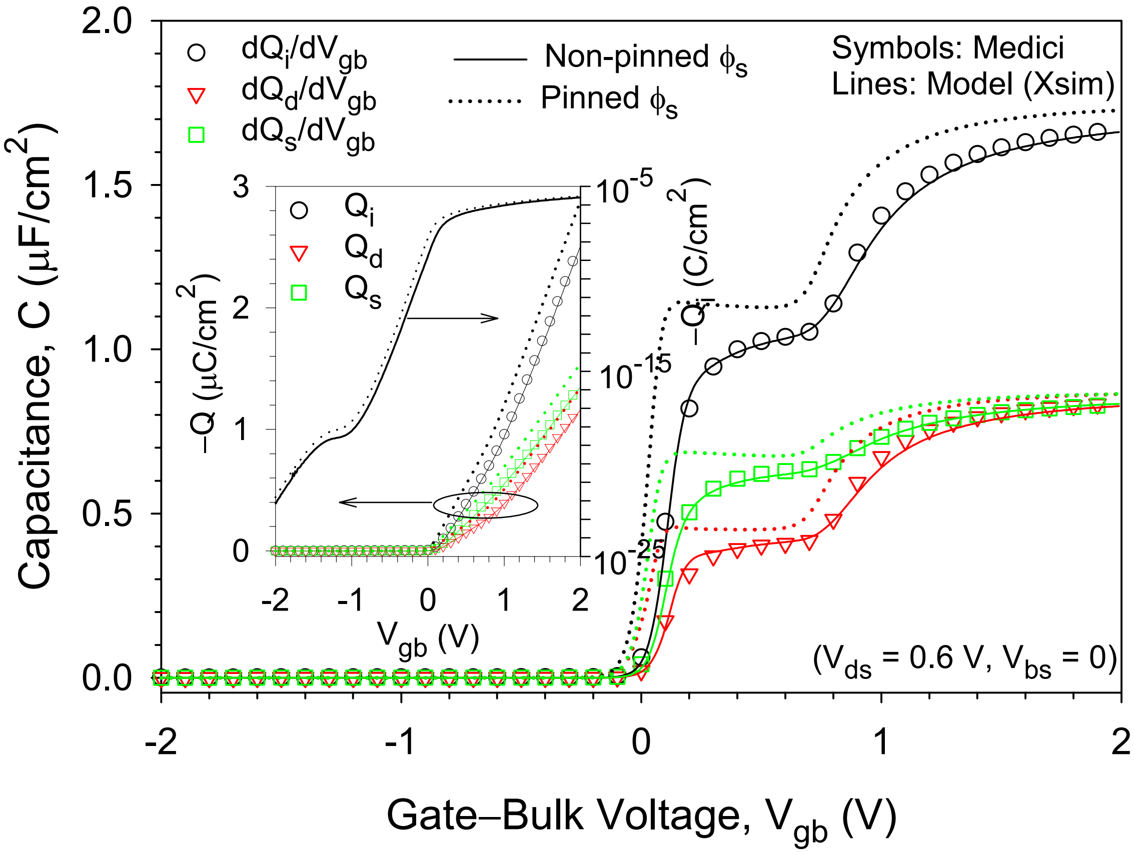
"Decomposable" Bulk Capacitance with Continuity



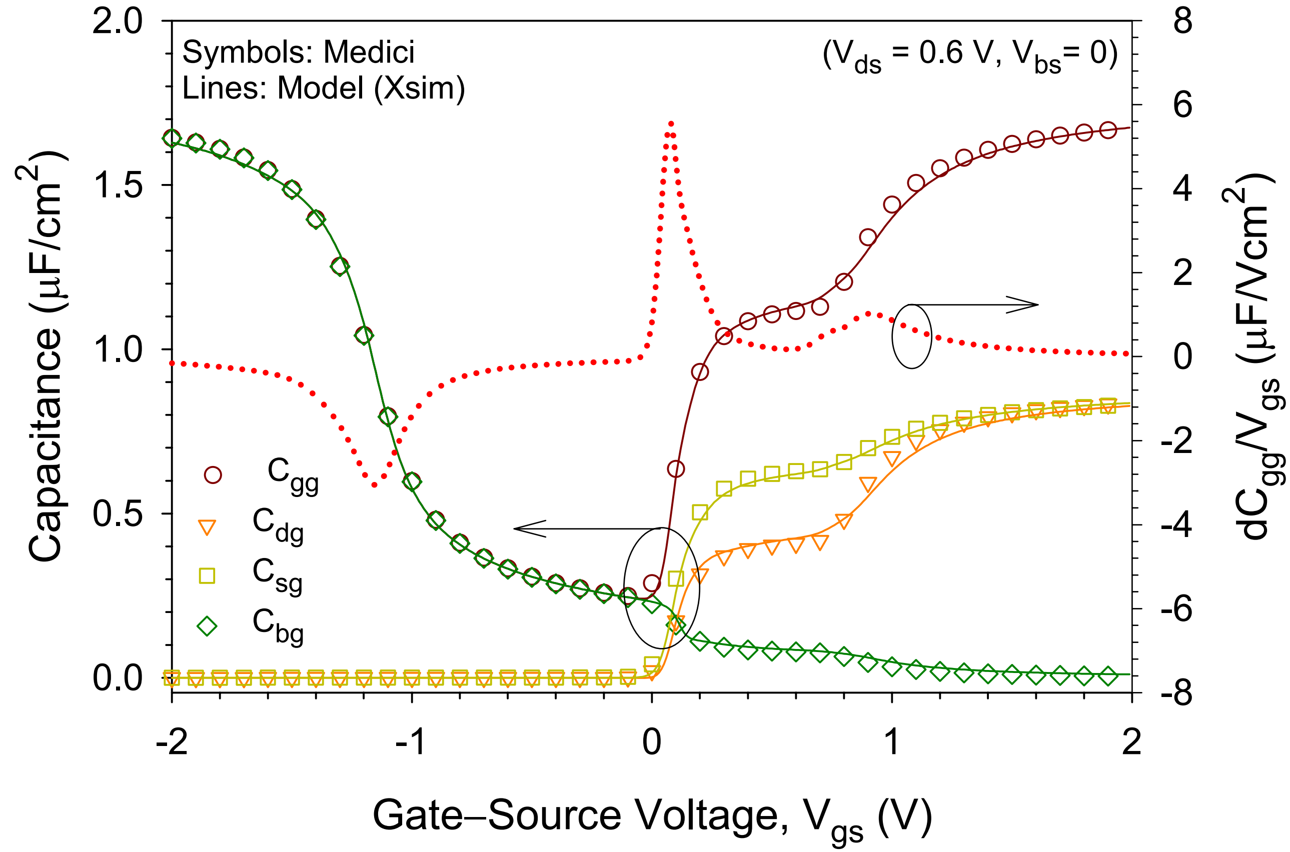
Single-piece Terminal Charges



Inversion Charges and Capacitances with Non-pinned ϕ_s



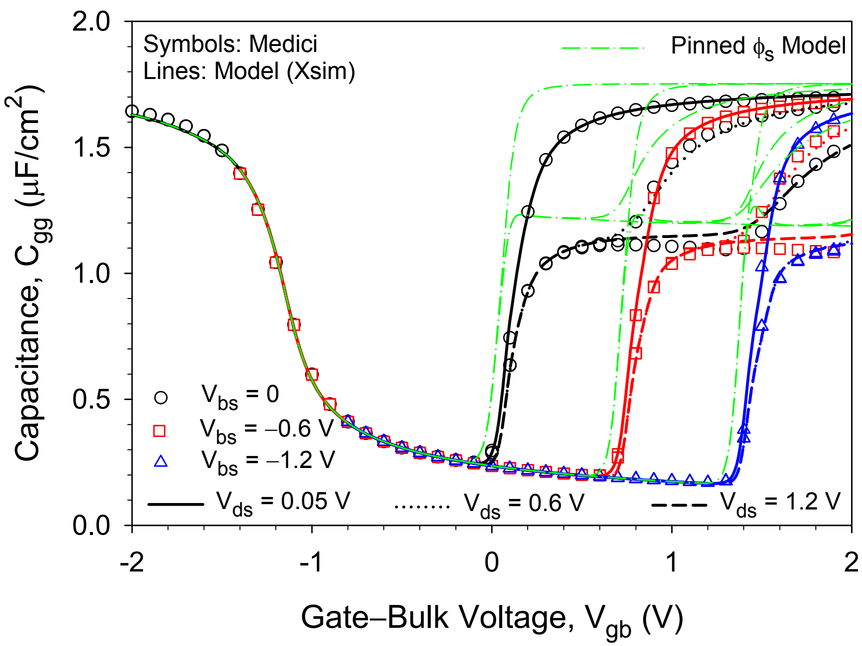
Transcapacitance and Charge Conservation



Single-piece Continuous C_{gg}, C_{bg} and C'_{bg} in *All* Regions

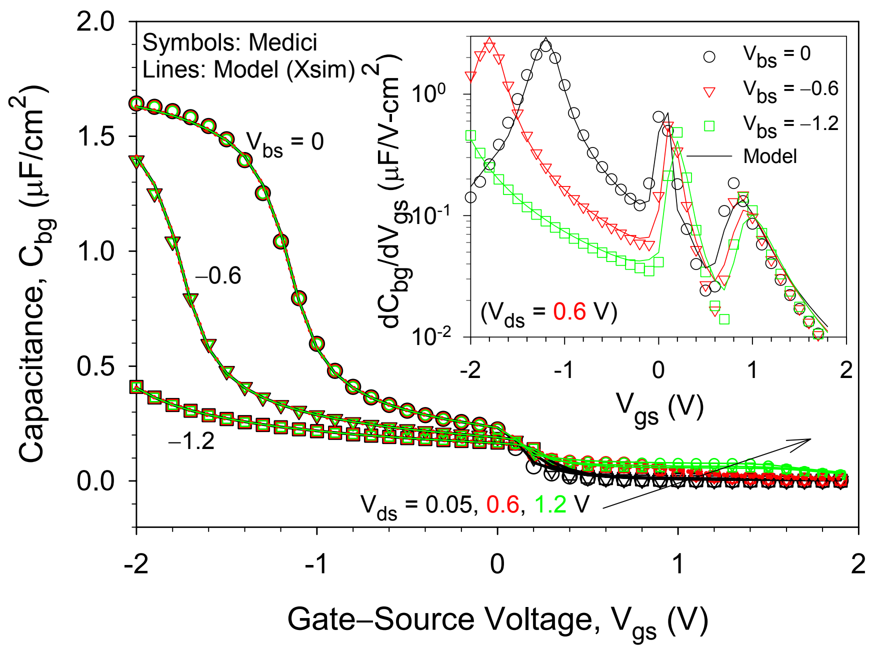
C_{gg} at various V_{ds}, V_{bs}

(Compared with pinned ϕ_s)

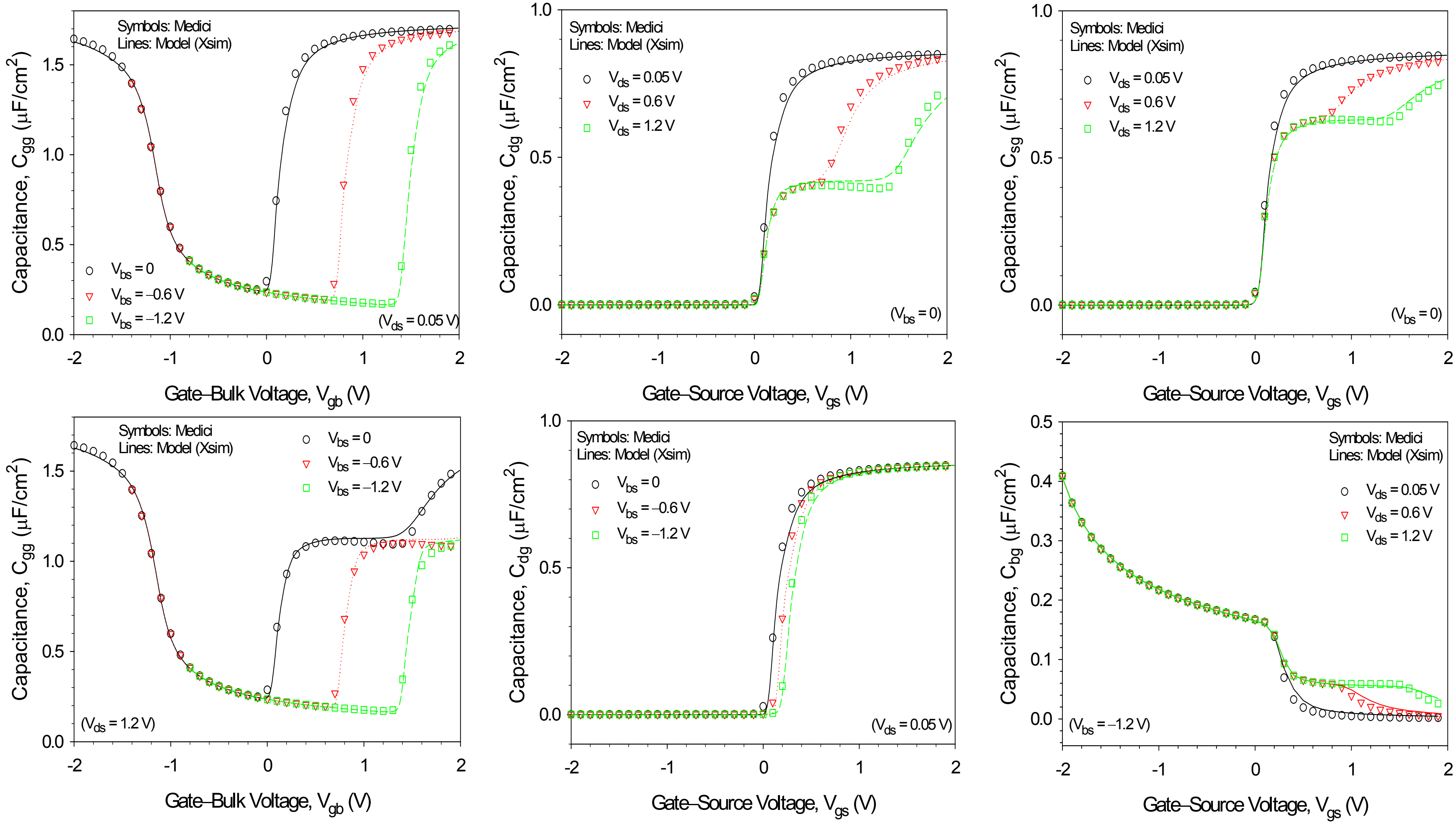


C_{bg} at various V_{ds}, V_{bs}

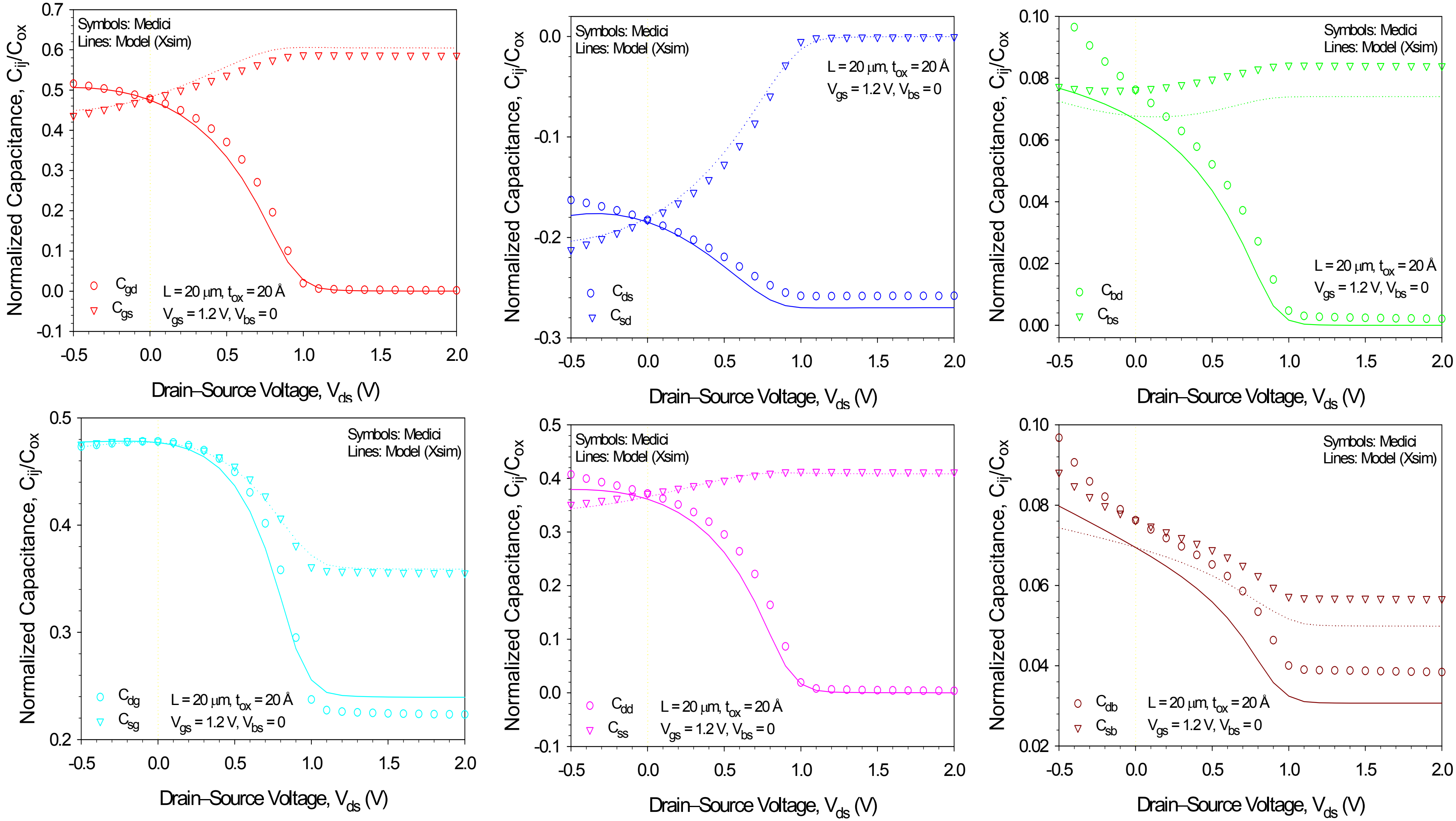
(Compared with Medici C'_{bg})



Bias-scalable C_{gg}, C_{dg}, C_{sg}, C_{bg} in *All* Regions



Transcapacitance Symmetry



"Pao–Sah" Equation for the Gate Surface Potential ϕ_p

$$\overline{V_{gb}-V_{fb}-\phi_s}-\phi_p=\operatorname{sgn}(\phi_p)\gamma_p\sqrt{f_{\phi,p}}$$
$$=\pm\gamma_p\sqrt{v_{th}\left[\exp\left(-\frac{\phi_p}{v_{th}}\right)-1\right]+\phi_p-\phi_p\exp\left(-\frac{2\phi_{F,p}}{v_{th}}\right)+v_{th}\exp\left(-\frac{2\phi_{F,p}}{v_{th}}\right)\left[\exp\left(\frac{\phi_p}{v_{th}}\right)-1\right]}\qquad (V_{cb}=0)$$

$$\phi_{p,ss}=\phi_{p0}+\Delta_p \longrightarrow \phi_{p,str}$$

$$\phi^*_{p,ss}=\phi_{p0}+\frac{\phi_{p,dd}-\phi_{p0}}{\sqrt{1+\left[\frac{\phi_{p,dd}-\phi_{p0}}{4v_{th}}\right]^2}}$$

$$\Delta_p=v_{th}\ln\left\{\frac{1}{v_{th}}\vartheta_f\left\{\left(\frac{V_{gap}}{\gamma_p}\right)^2-\phi_{p0};\rho_{eff}\right\}+1\right\}$$

$$V_{gap}=\vartheta_f\left\{V_{gb}-V_{fb}-\phi_s-\phi^*_{p,str};\rho_{vga}\right\}$$

Coupling to ϕ_s:

$\phi_s=\phi_{seff}$ in ϕ_{peff}

$\overline{V_{gb}-V_{fb}-\phi_{peff}}$ in ϕ_{seff}

$$\phi_{p,dd}=\left(-\frac{\gamma}{2}+\sqrt{\frac{\gamma^2}{4}+\overline{V_{gb}-V_{fb}-\phi_s}}\right)^2$$

$$V_{gbs}=\vartheta_f\left\{V_{gb}-V_{fb}-\phi_s;\rho_f\right\} \longrightarrow \phi_{p,sub}$$

$$\phi_{p,cc}=-v_{th}\ln\left[\frac{\gamma^2}{\gamma_p^2}\exp\left(-\frac{\phi_s}{v_{th}}\right)+\left(1-\frac{\gamma^2}{\gamma_p^2}\right)\right]$$

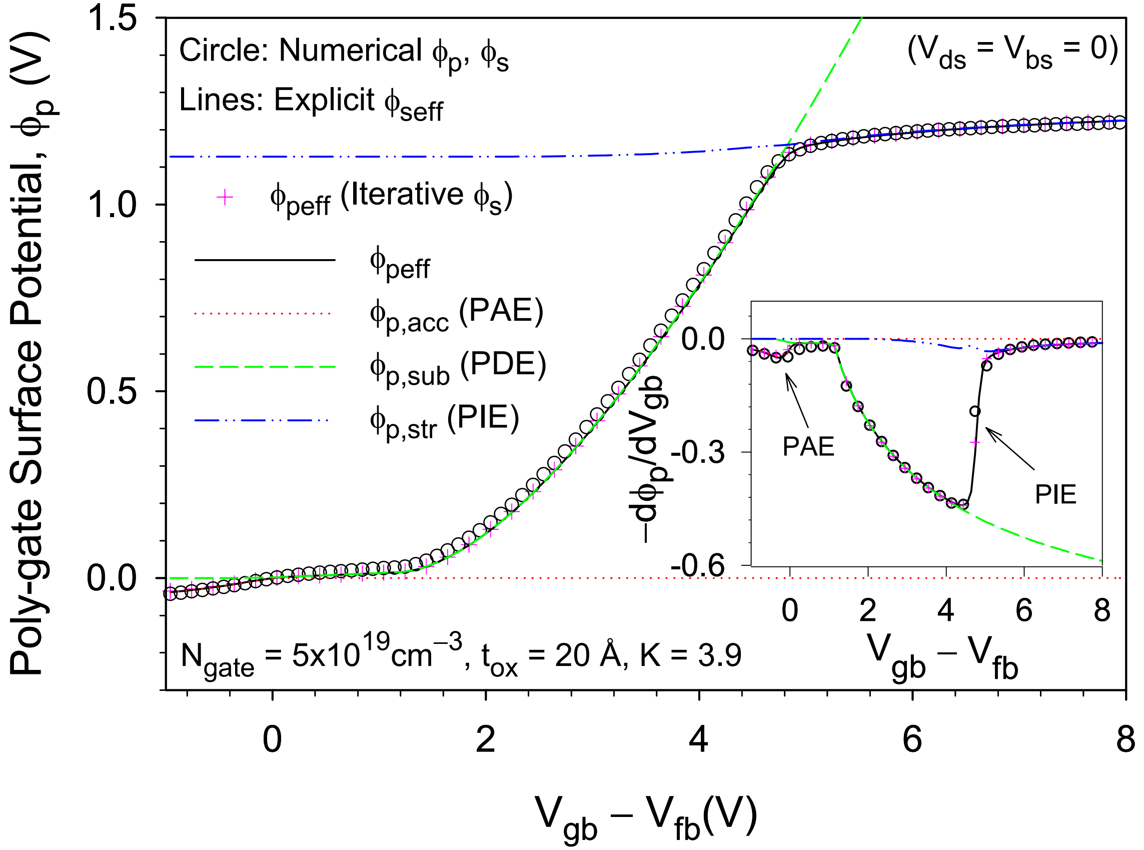
$$\phi_s\to\phi_{sr}=\vartheta_r\left\{\phi_s;\rho_r\right\} \longrightarrow \phi_{p,acc}$$

+ =

$$\phi_{pa}=\phi_{p,acc}+\phi_{p,sub}$$

$$\phi_{peff}=\vartheta_{eff}\left\{\phi_{pa},\phi_{p,str};\delta_\rho\right\}$$

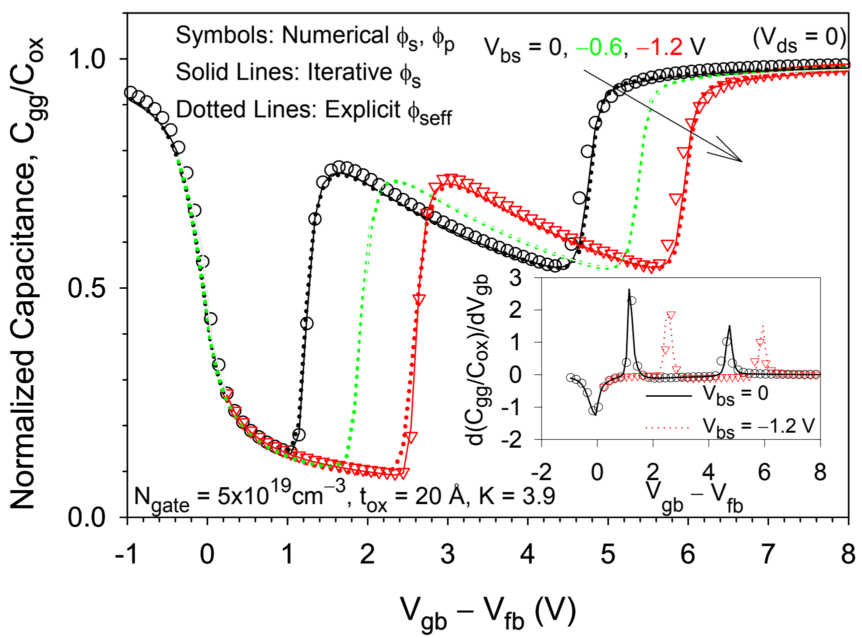
Unified Regional Poly-gate Surface Potential



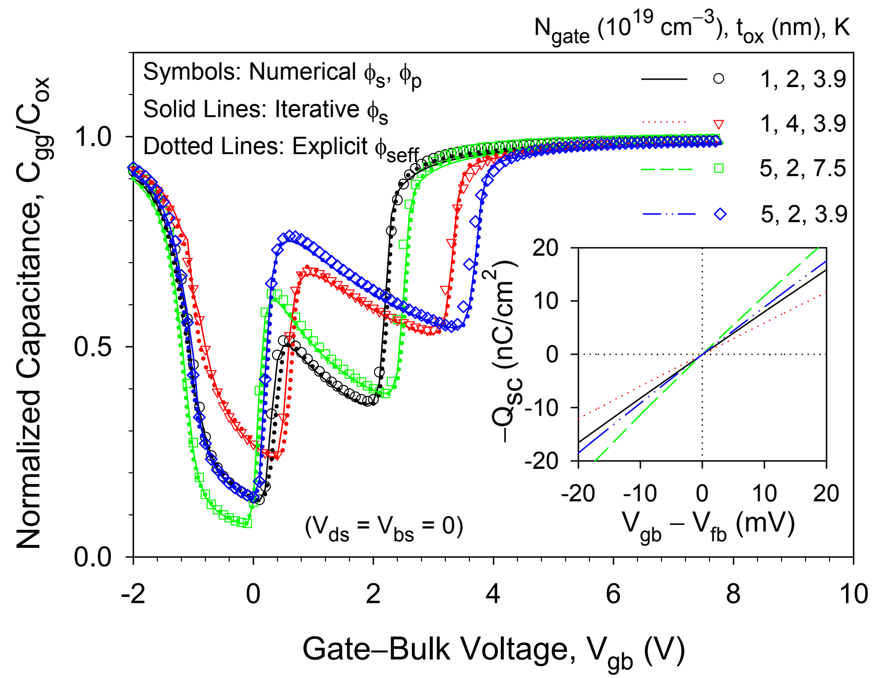
[To appear in ***Appl. Phys. Lett.***, vol. 86, no. 20, 16 May 2005.]

Poly-Accumulation/Depletion/Inversion Effects

Smooth bias-scalable

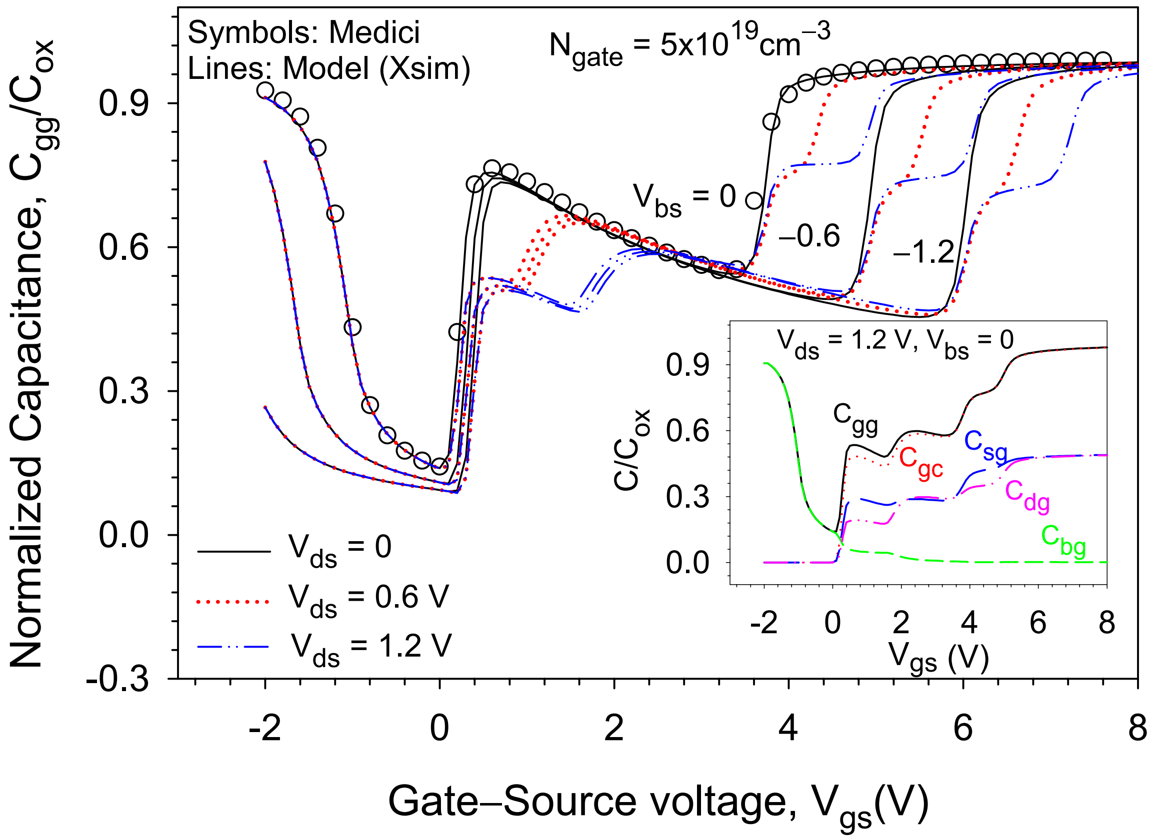


Physical N_{gate}/t_{ox}/K-scalable



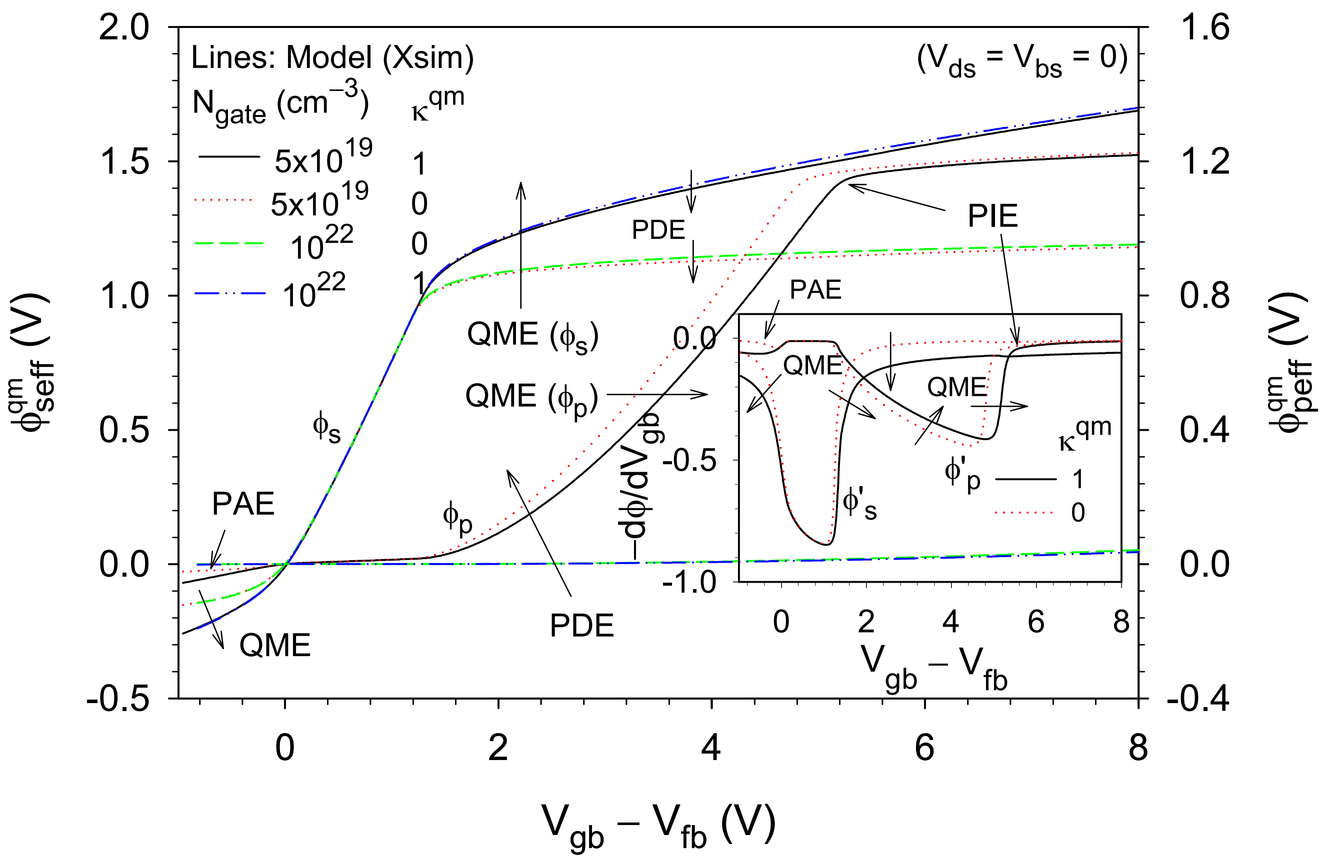
[To appear in ***Appl. Phys. Lett.***, vol. 86, no. 20, 16 May 2005.]

Unified Charge-based PAE/PDE/PIE Capacitance Model



Explicit ϕ_{seff} and ϕ_{peff} with Decoupled QME and PAE/PDE

"van Dort": $\Delta E_g^{qm} \equiv E_g^{qm} - E_g = \frac{3\hbar^2}{8m^*}\left[\frac{12m^* q^2}{\varepsilon_{Si}\hbar^2}\frac{2C_{ox}\left(V_{gb} - V_{fb} - \phi_s\right)/q}{3}\right]^{2/3}$ → $n_i^{qm} = n_i \exp\left(-\Delta\phi_s^{qm}/v_{th}\right)$



Two coupled Pao–Sah equations for ϕ_s and ϕ_p, both with:

$$\Delta\phi_s^{qm}(\phi_s) \equiv \kappa^{qm}\Delta E_g^{qm}/2q$$

Decoupled explicit ϕ_{seff}^{qm} and ϕ_{peff}^{qm}, including QME

$$\phi_{seff}^{qm} = \phi_{acc}^{qm} + \phi_{ds}^{qm}$$

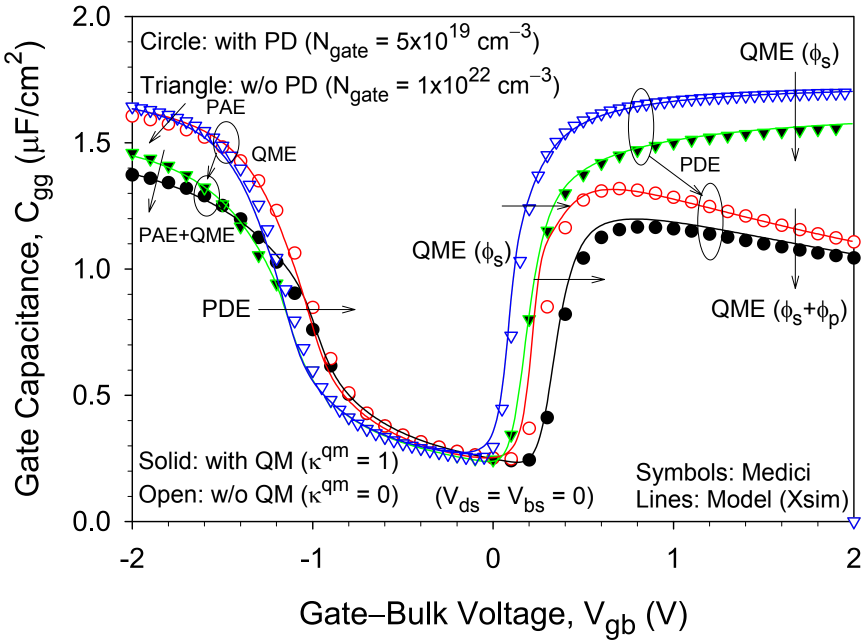
$$\phi_{ds}^{qm} = \vartheta_{eff}\left\{\phi_{sub}^{qm}, \phi_{str}^{qm}; \delta_\phi\right\}$$

$$\phi_{peff}^{qm} = \vartheta_{eff}\left\{\phi_{pa}^{qm}, \phi_{p,str}^{qm}; \delta_\rho\right\}$$

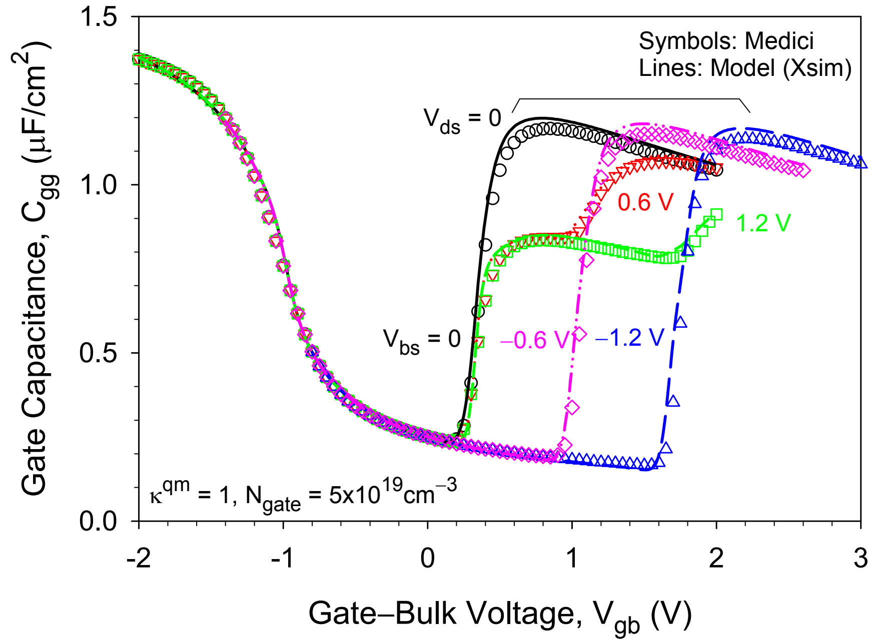
$$\phi_{pa}^{qm} = \phi_{p,acc}^{qm} + \phi_{p,sub}^{qm}$$

Bias-scalable Charge Model for Combined QME/PDE/PAE

Separate QME/PDE/PAE

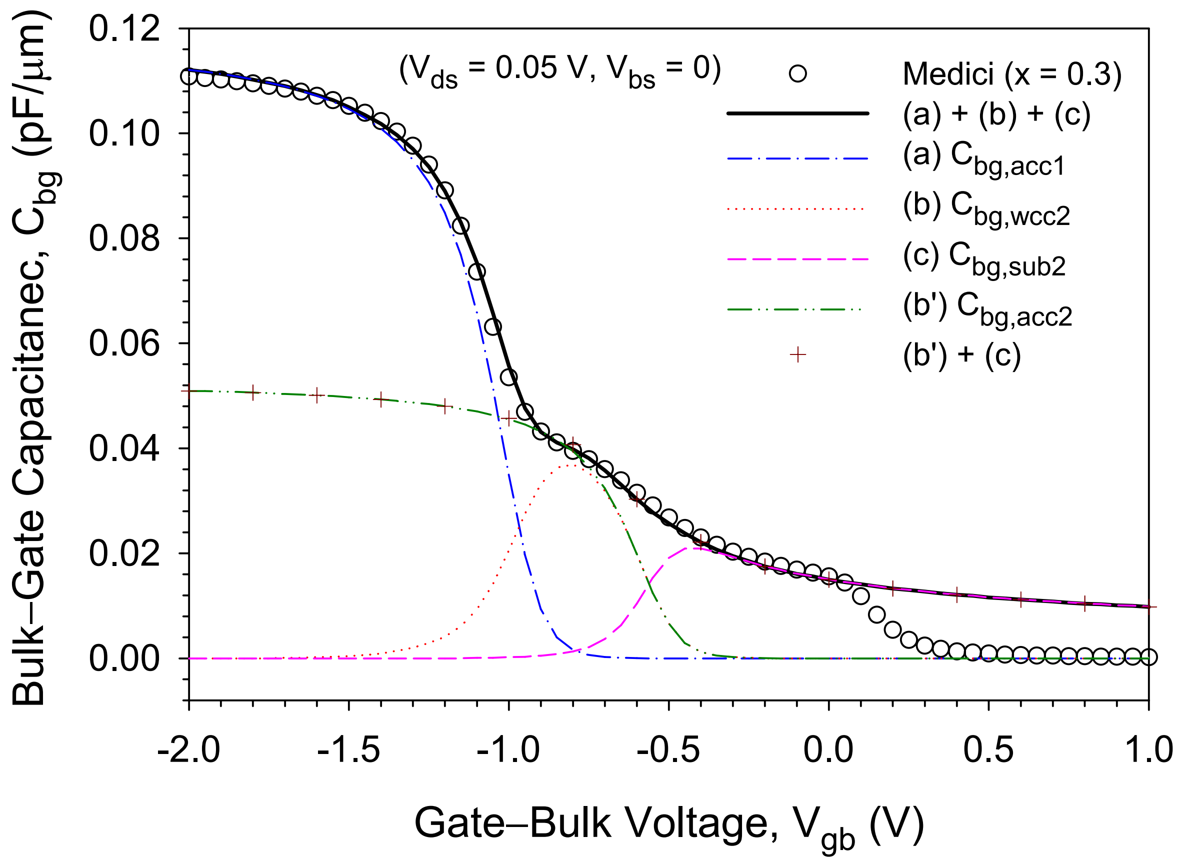


Drain/bulk-bias variation



This is believed to be the first single-piece explicit model combining all QME, PDE, PAE, PIE.

Extension to Strained-Si with Unified Regional Modeling

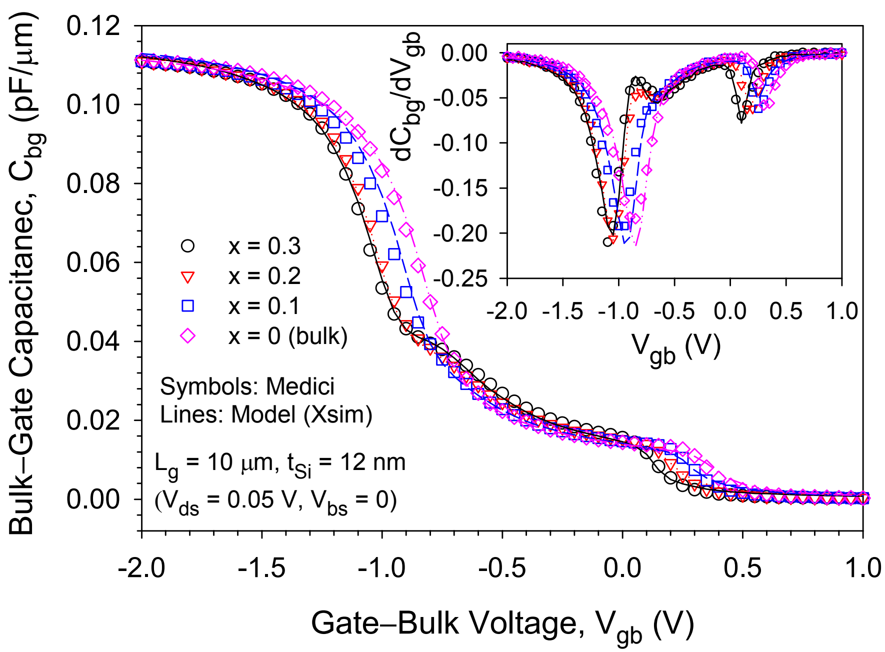


[To appear in ***IEEE Trans. Electron Devices***, 2005.]

Predicting Strained-Si C_{bg} and C'_{bg}

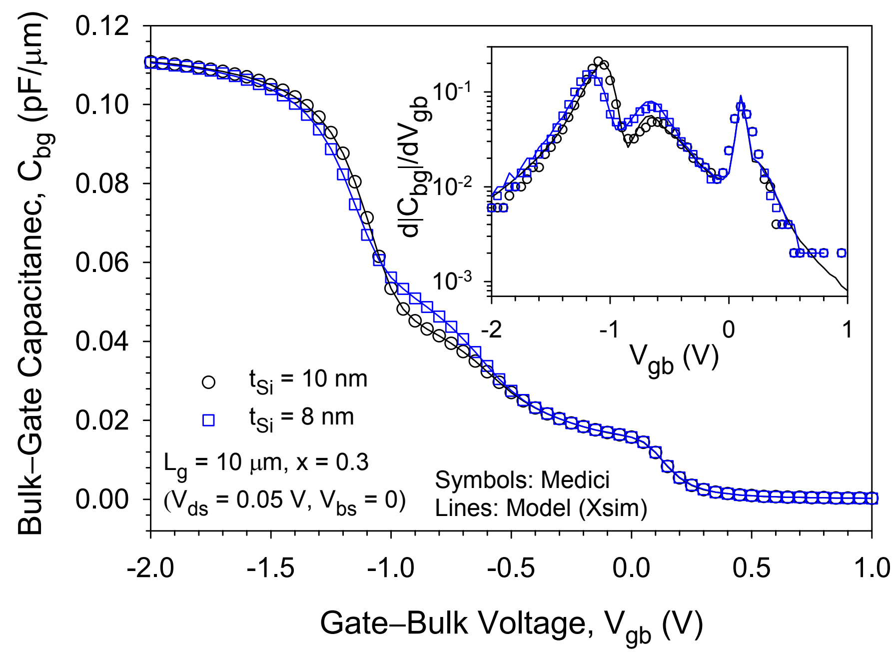
Ge mole fraction variation

(x = 0 ~ 0.3)



s-Si thickness variation

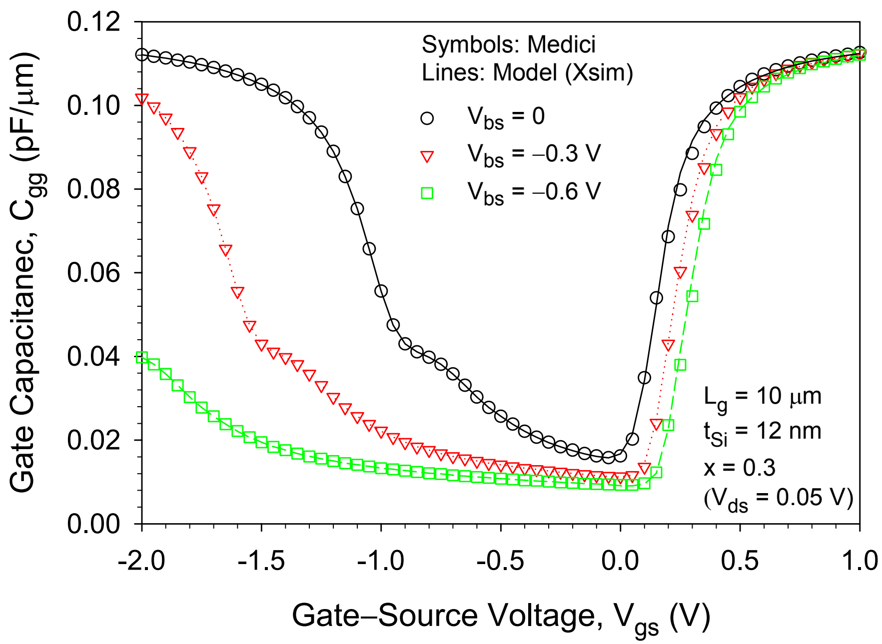
(t_{Si} = 8 ~ 10 nm)



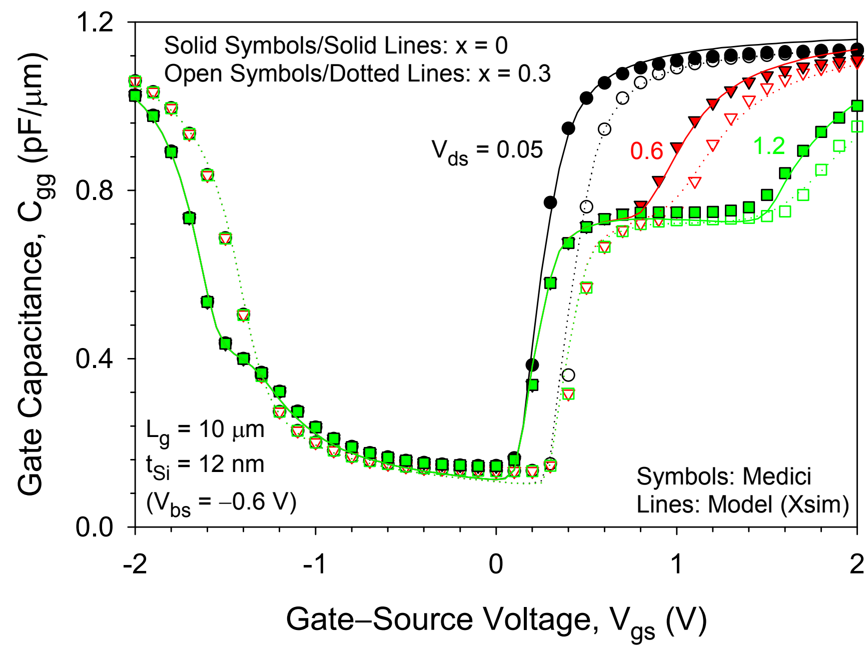
[To appear in ***IEEE Trans. Electron Devices***, 2005.]

Predicting Strained-Si C_{gg}

Bulk-bias variation



Drain-bias variation

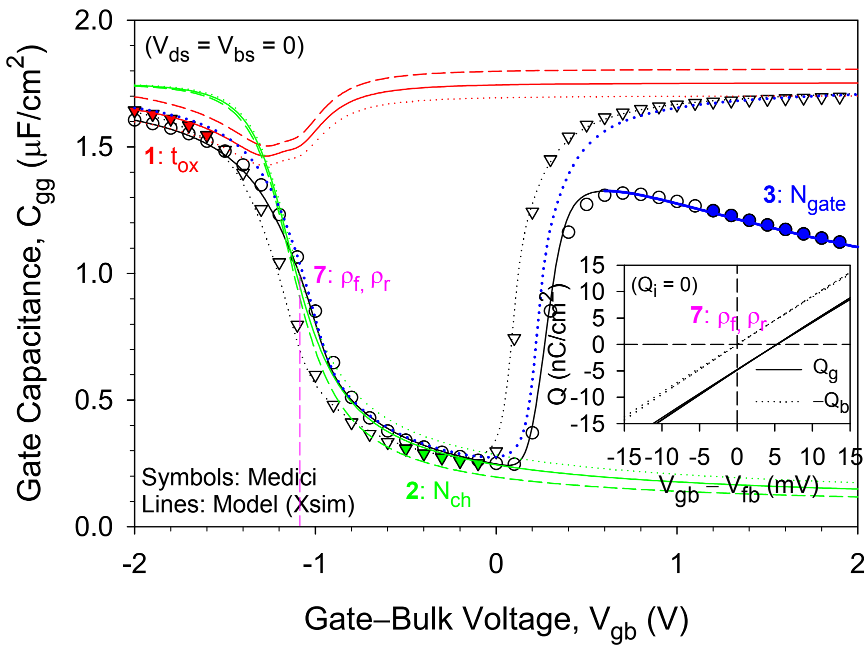


[To appear in ***IEEE Trans. Electron Devices***, 2005.]

One-iteration AC Parameter Extraction

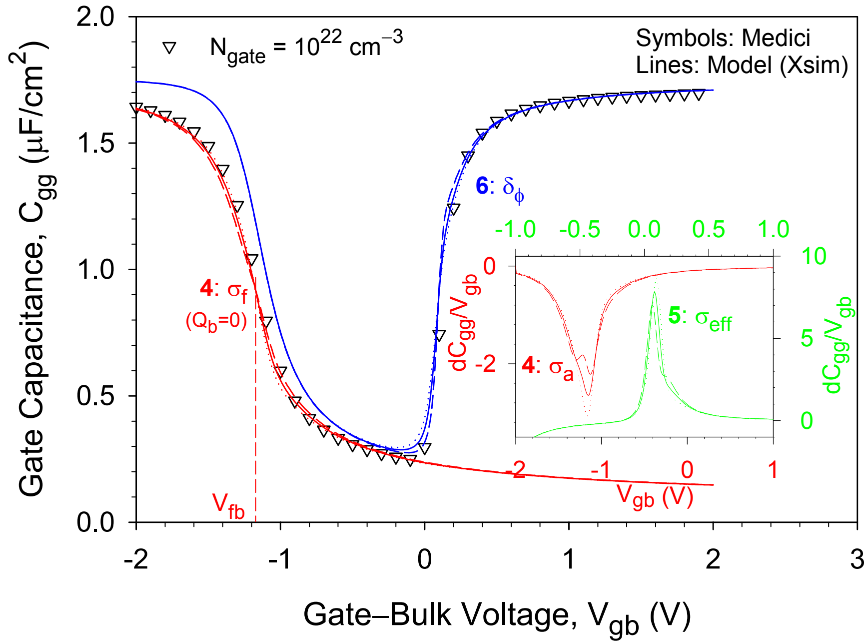
Physical parameters

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



Smoothing parameters

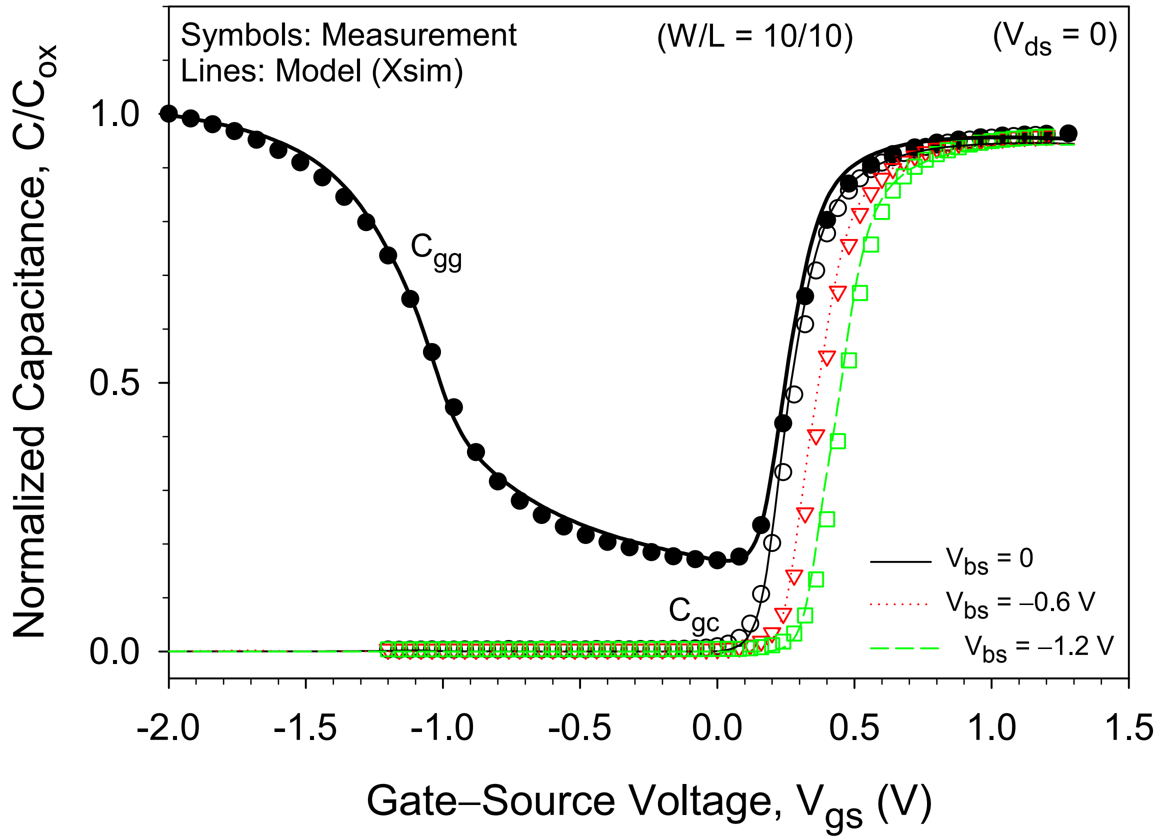
(σ_a, σ_f; σ_{eff}, δ_ϕ; ρ_f, ρ_r)



One C_{gg} data for *physical* parameter extraction. *Smoothing* parameters are determined by model requirements.

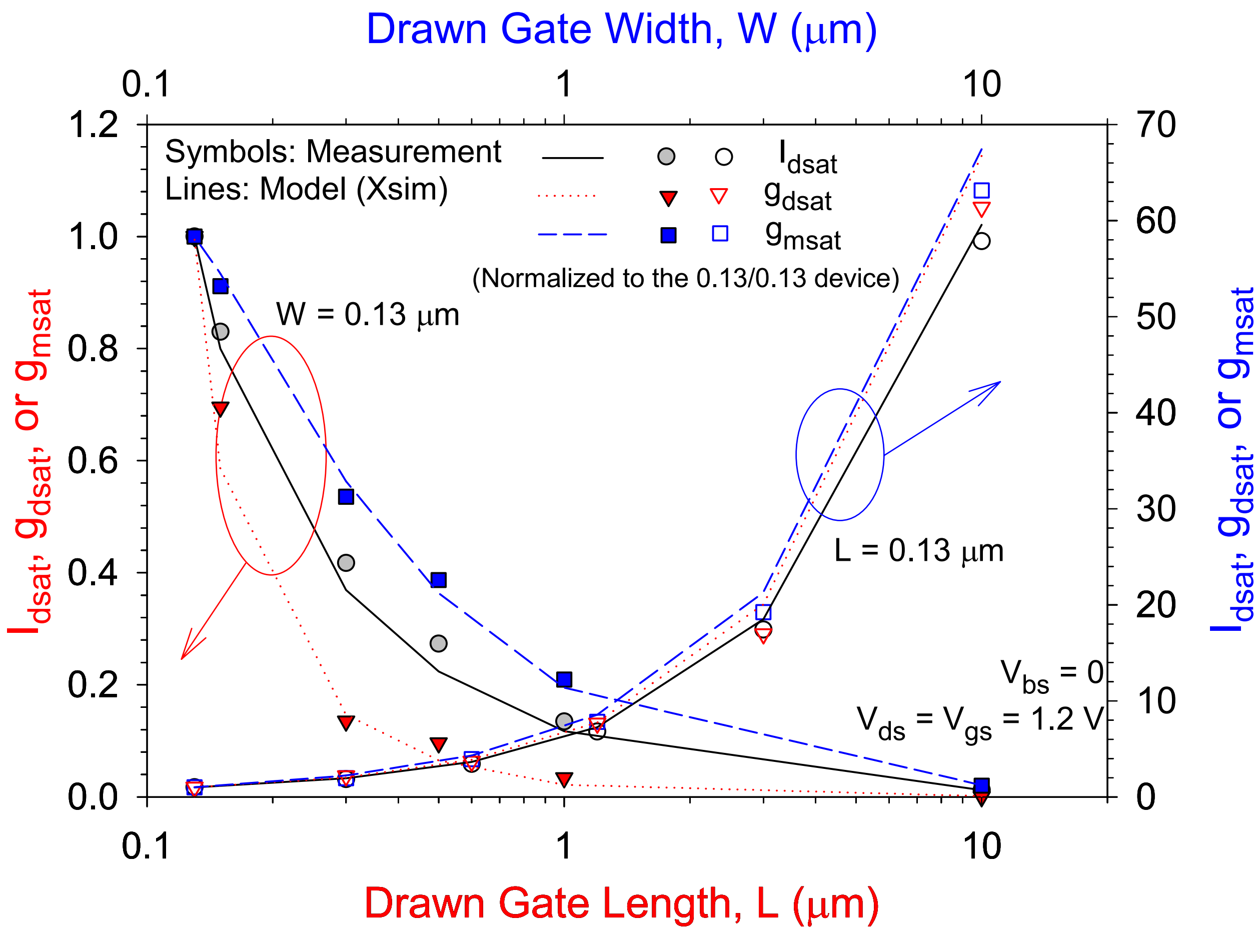
[See details in ***WCM2005***, poster presentation by S. B. Chiah.]

Extracted Model from One Measured C_{gg} Data



[See details in ***WCM2005***, poster presentation by S. B. Chiah.]

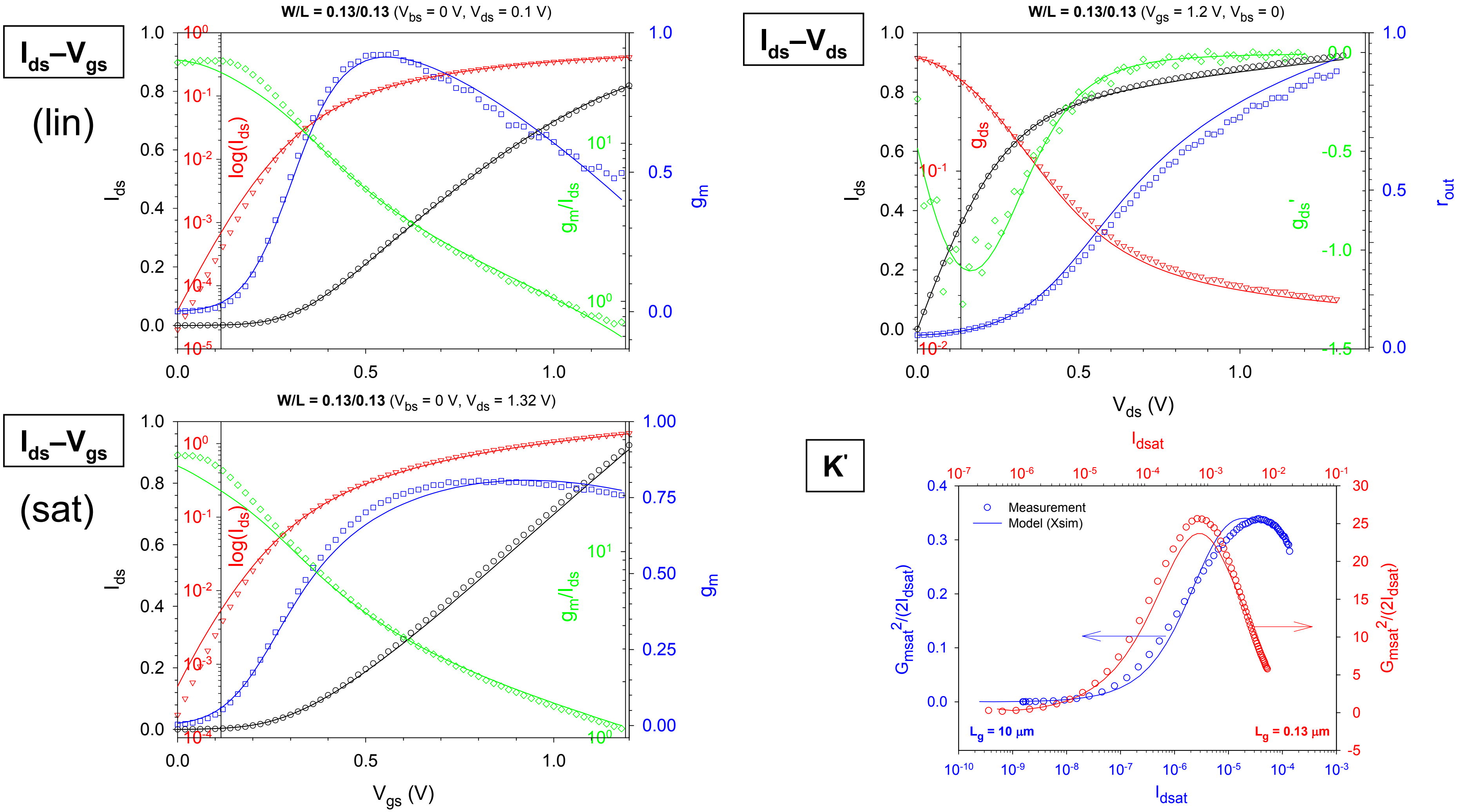
Predicted I_{dsat}, g_{dsat}, g_{msat} Over Geometries



- <u>Minimum data</u> for model calibration:
  - V_t – L, W @ corner biases
  - Point I_{dsat}, g_{ds0} data
  - Only **6** I – V data
- <u>One-iteration</u> model extraction
  - Step-by-step
  - Second iteration for improvement
- <u>Prediction</u> over the entire geometry and bias, including higher-order derivatives

[See details in ***WCM2005***, poster presentation by S. B. Chiah.]

Short/Narrow Device DC and Gain-Factor Prediction



Summary and Conclusions

- **Regional charge-based approach with non-pinned surface potential** — combines the best features of $\phi_s/Q_i/V_t$-based approaches
- **Coupled explicit solution with QME and PAE/PDE/PIE** — built into the regional Pao–Sah solutions
- **Easy extension to future MOS structures** — strained-Si (FD/PD-SOI, DG)
- **Minimum data with one/two-iteration extraction** — scalable & predictive
- **Simple and familiar formulation with selectable accuracy** — trade-off accuracy/speed within one parameter set
- **Concluding remark**: all the above combined features may be challenging to achieve with one particular (ϕ_s, Q_i, V_t) approach. Our approach and effort provide another option towards the development of next generation compact models for circuit simulation.

Acknowledgment and References

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  - ***Semiconductor Research Corporation***: Contract No. 2004-VJ-1166
  - ***Nanyang Technological University***: Grant RGM30/03

- **Recent publications**

  - "A compact gate-current model based on transfer matrix method," to appear in ***J. Appl. Phys.***, Vol. 97, No. 11, 1 June 2005.
  - "Physics-based single-piece charge model for strained-Si MOSFETs," to appear in ***IEEE Trans. Electron Devices***, 2005.
  - "Single-piece polycrystalline silicon accumulation/depletion/inversion model with implicit/explicit surface-potential solutions," to appear in ***Appl. Phys. Lett.***, Vol. 86, No. 20, 16 May 2005.
  - "A compact model for future generation predictive technology modeling and circuit simulation," (***Invited Paper***), to be presented at the ***MIXDES 2005***, Kraków, Poland, June 23, 2005.
  - "Unified regional charge model with non-pinned surface potential," (***Invited Paper***), *Proc.* ***IWCM-2005***, pp. 13–17, presented at the ***ASP-DAC2005***, Shanghai, Jan. 20, 2005.
  - "Xsim: unified regional approach to compact modeling for next generation CMOS," (***Invited Paper***), *Proc.* ***ICSICT-2004***, pp. 924–929, Beijing, Oct. 19, 2004.