



A Continuous Surface Potential versus Voltage Model for Undoped Symmetric Double-Gate MOSFETs

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Outlines

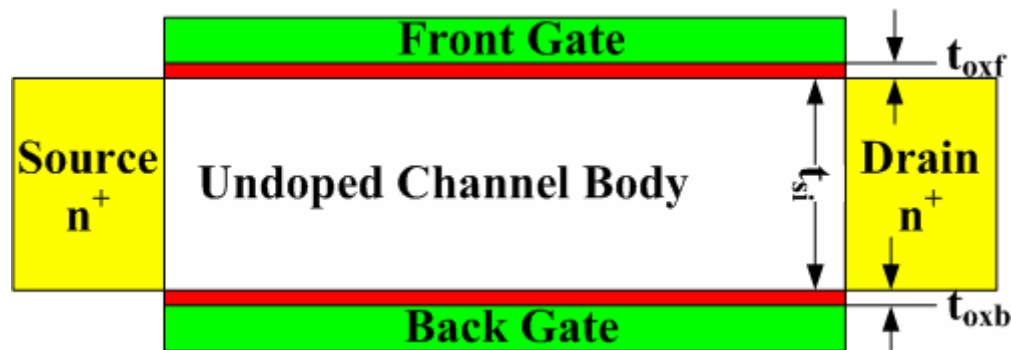
- ◆ **Introduction to DG Modeling**
- ◆ **Surface Potential-Voltage Equations and the Solutions**
- ◆ **Results**



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Double Gate MOSFET



- ◆ Better control of the channel region
- ◆ Higher current drive per unit silicon area
- ◆ Better performance in avoiding SCEs:
DIBL and sub-threshold slope

J. -P. Colinge, "Multiple-gate SOI MOSFETs,"
Solid-State Electron. Vol. 48, no. 6, pp. 897-905, June 2004.



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DG Modeling

Surface-potential-based model:

**More physical and accurate description
of transistor behavior;**

**More popular in the compact modeling
community;**



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DG Modeling

A singularity in the mathematics:

Near flat-band voltage;

May affect continuity and convergence;

A complete and continuous surface potential equation of DG MOSFETs has not been established.



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DG Modeling

What is new?

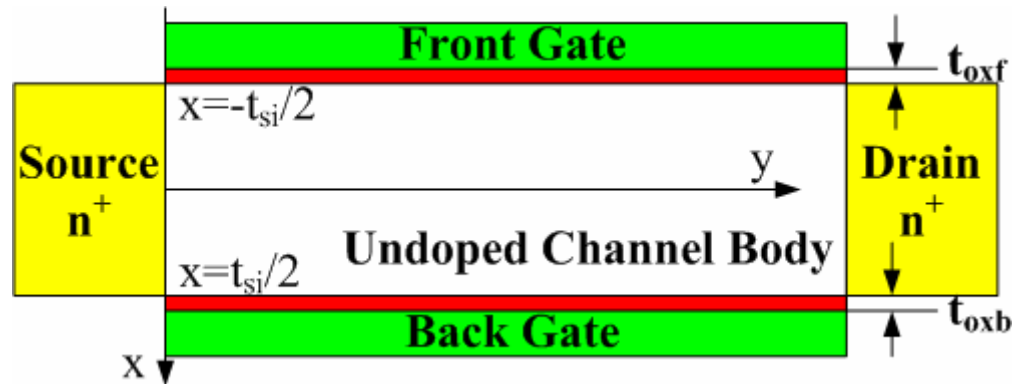
- Smooth and continuous
- Single surface-Potential versus Voltage Equation
- From accumulation to strong inversion region
- Accuracy over a wide range of biases and geometry parameters



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Surface Potential Equation



Poisson's Equation:

$$\frac{d^2 \phi}{dx^2} = \frac{qn_i}{\epsilon_{si}} \left[e^{\frac{q(\phi-V)}{kT}} - e^{\frac{-q\phi}{kT}} \right]$$

Boundary Conditions:

$$\frac{d\phi}{dx}(x=0) = 0, \frac{d\phi}{dx}(x = \pm \frac{t_{si}}{2}) = C_{ox} (V_{gs} - \phi_s - \Delta\phi_i);$$

$$\phi(x = \pm \frac{t_{si}}{2}) = \phi_s, \phi(x=0) = \phi_0;$$



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Surface Potential Equation

Considering Electrons and Holes Separately:

$$\phi_s = \phi_0 - \frac{2kT}{q} \ln \cos \left[\frac{t_{si}}{2} \sqrt{\frac{q^2 n_i}{2\epsilon_{si} kT} e^{\frac{q(\phi_0 - V)}{kT}}} \right]; (*)$$

$$\phi_s = \phi_0 + \frac{2kT}{q} \ln \cos \left[\frac{t_{si}}{2} \sqrt{\frac{q^2 n_i}{2\epsilon_{si} kT} e^{-\frac{q\phi_0}{kT}}} \right]; (*)$$

Gauss's Law:

$$C_{ox} (V_{gs} - \phi_s - \Delta\phi_i) = \epsilon_{Si} \left. \frac{d\phi}{dx} \right|_{x=\pm \frac{t_{si}}{2}}$$

* Y. Chen and J. Luo, "A comparative study of double-gate and surrounding-gate MOSFETs in strong inversion and accumulation using an analytical model". *Proceedings of the Conference on Modeling and Simulation of Microsystems*, 2001, pp. 546-549.



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Surface Potential Equation

$$\left\{ \frac{C_{ox} (V_{gs} - \Delta\phi_i - \phi_s)}{\sqrt{2n_i \varepsilon_{si} kT}} e^{\frac{q(\phi_s - V)}{2kT}} = \right. \quad \dots (13)$$

$$\left. \sin \left[\frac{t_{si}}{2} \sqrt{\frac{q^2 n_i}{2\varepsilon_{si} kT}} \left[e^{\frac{q(\phi_s - V)}{kT}} - \frac{C_{ox}^2 (V_{gs} - \Delta\phi_i - \phi_s)^2}{2n_i \varepsilon_{si} kT} \right] \right] \right. \quad , V_{GS} > \Delta\phi_i$$

$$\left\{ \frac{C_{ox} (V_{gs} - \Delta\phi_i - \phi_s)}{\sqrt{2n_i \varepsilon_{si} kT}} e^{\frac{q\phi_s}{2kT}} = \right. \quad \dots (22)$$

$$\left. -\sin \left[\frac{t_{si}}{2} \sqrt{\frac{q^2 n_i}{2\varepsilon_{si} kT}} \left[e^{-\frac{q\phi_s}{kT}} - \frac{C_{ox}^2 (V_{gs} - \Delta\phi_i - \phi_s)^2}{2n_i \varepsilon_{si} kT} \right] \right] \right. \quad , V_{GS} \leq \Delta\phi_i$$



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Surface Potential Equation

With two modifications:

$$\frac{C_{ox}(V_{gs} - \Delta\phi_i - \phi_s)}{\sqrt{2n_i\varepsilon_{si}kT}} \left[e^{\frac{q(\phi_s - V)}{kT}} - \left(1 + \frac{q\phi_s}{kT} \right) e^{-\frac{qV}{kT}} \right]^{-\frac{1}{2}} = \dots (15)$$

$$\sin \left[\frac{t_{si}}{2} \sqrt{\frac{q^2 n_i}{2\varepsilon_{si}kT}} \left[e^{\frac{q(\phi_s - V)}{kT}} - \left(1 + \frac{q\phi_s}{kT} \right) e^{-\frac{qV}{kT}} - \frac{C_{ox}^2 (V_{gs} - \Delta\phi_i - \phi_s)^2}{2n_i\varepsilon_{si}kT} \right] \right], V_{GS} > \Delta\phi_i$$

$$\frac{C_{ox}(V_{gs} - \Delta\phi_i - \phi_s)}{\sqrt{2n_i\varepsilon_{si}kT}} \left[e^{-\frac{q\phi_s}{kT}} - 1 + \frac{q\phi_s}{kT} \right]^{-\frac{1}{2}} = \dots (24)$$

$$-\sin \left[\frac{t_{si}}{2} \sqrt{\frac{q^2 n_i}{2\varepsilon_{si}kT}} \left[e^{-\frac{q\phi_s}{kT}} - 1 + \frac{q\phi_s}{kT} - \frac{C_{ox}^2 (V_{gs} - \Delta\phi_i - \phi_s)^2}{2n_i\varepsilon_{si}kT} \right] \right], V_{GS} \leq \Delta\phi_i$$





Surface Potential Equation

θ : Effect of the Quasi-Fermi-Potential

$$\theta = \begin{cases} e^{-qV_{ch}/kT} & \text{above flat-band point} \\ 1 & \text{below flat-band} \end{cases}$$

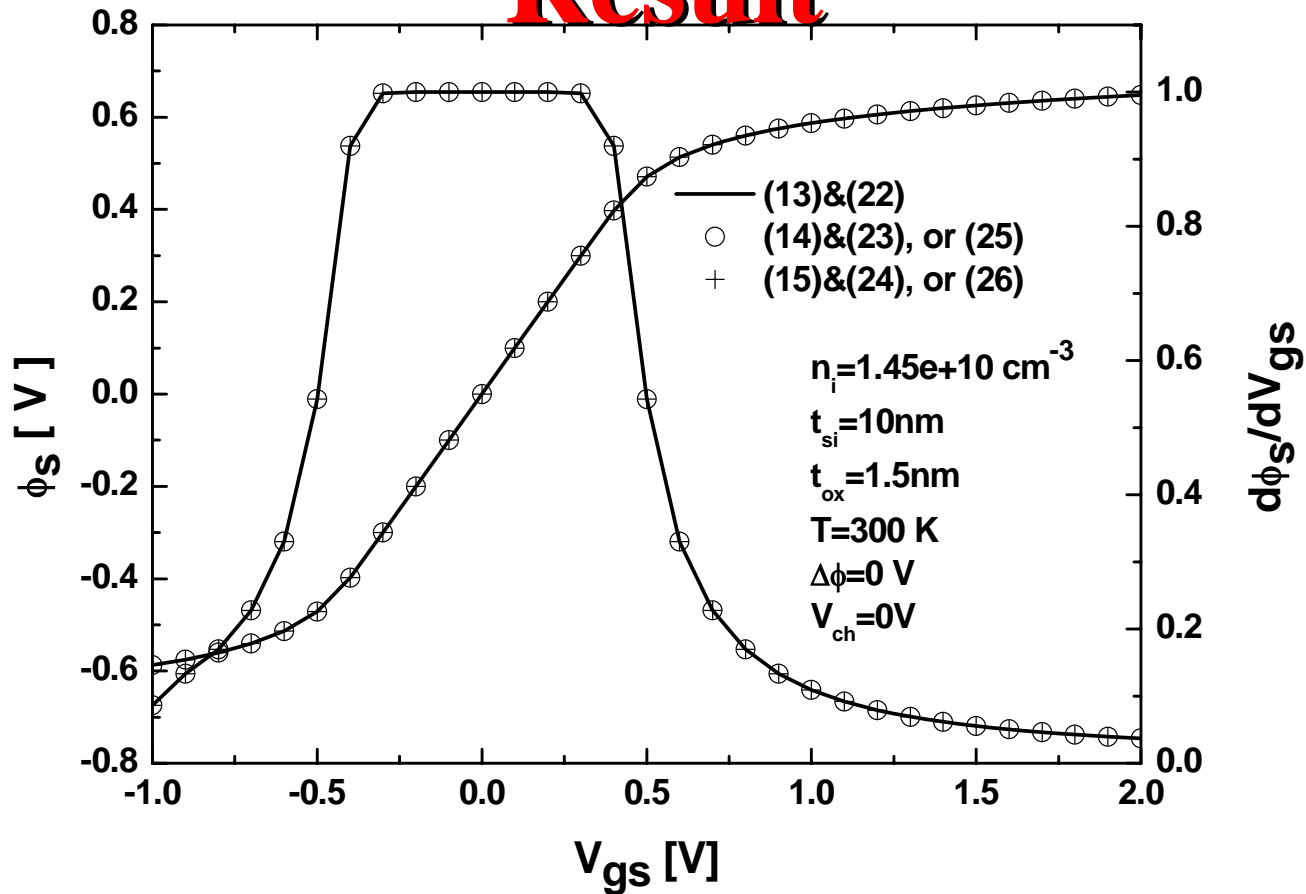
$$\frac{C_{ox}(V_{gs} - \Delta\phi_i - \phi_s)}{\sqrt{2n_i\varepsilon_{si}kT}} \left[\theta e^{\text{sgn}(\phi_s)\frac{q\phi_s}{kT}} - \left(1 + \text{sgn}(\phi_s)\frac{q\phi_s}{kT} \right) \theta \right]^{-\frac{1}{2}} = \dots \quad (26)$$

$$\text{sgn}(\phi_s) \sin \left[\frac{t_{si}}{2} \sqrt{\frac{q^2 n_i}{2\varepsilon_{si} kT}} \left[\theta e^{\text{sgn}(\phi_s)\frac{q\phi_s}{kT}} - \left(1 + \text{sgn}(\phi_s)\frac{q\phi_s}{kT} \right) \theta - \frac{C_{ox}^2 (V_{gs} - \Delta\phi_i - \phi_s)^2}{2n_i\varepsilon_{si}kT} \right] \right]$$





Result

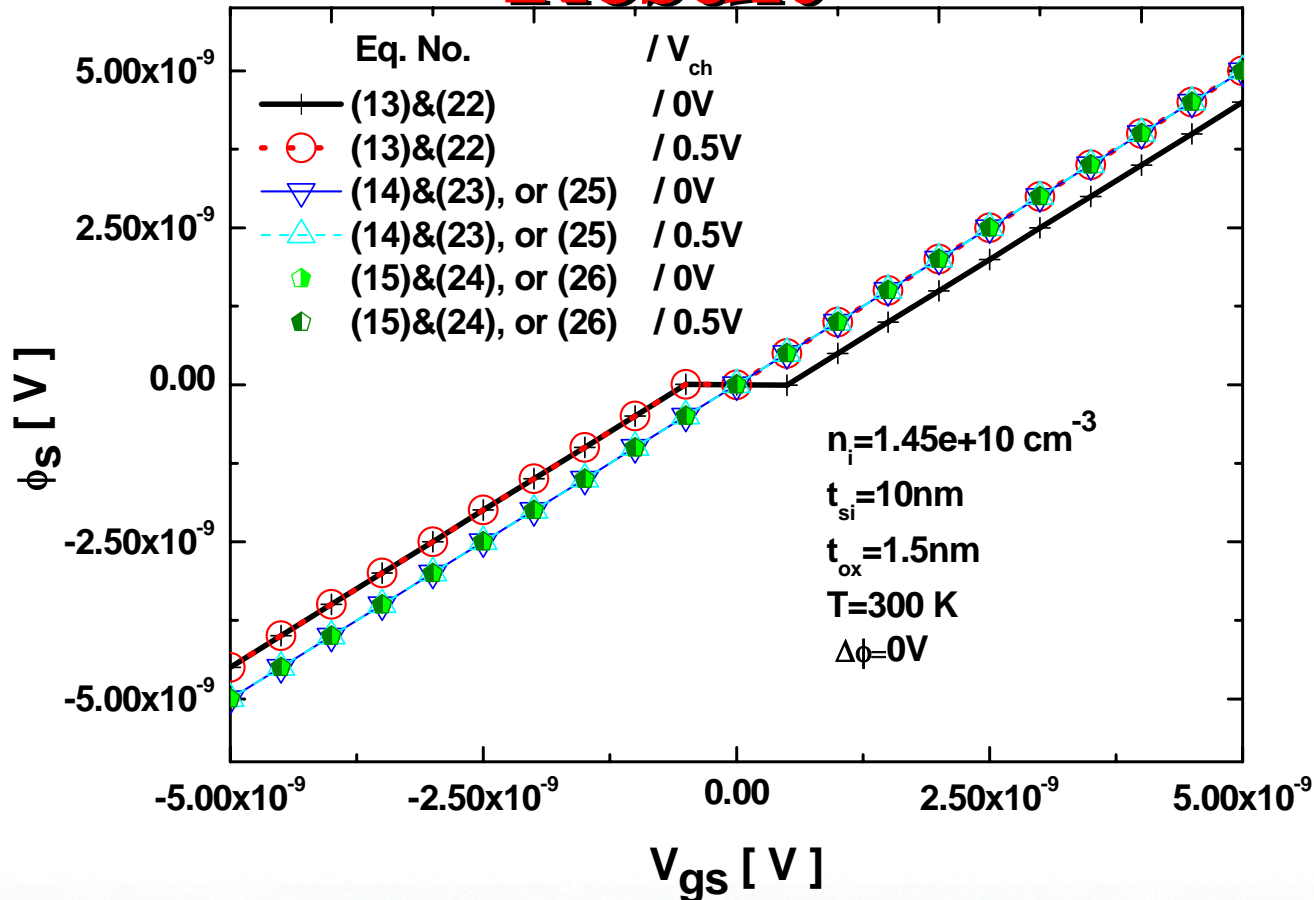


The surface potential and its derivative comparison of a DG MOSFET between three equation pairs for a wide gate voltage range ((left) and (right)).



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Result

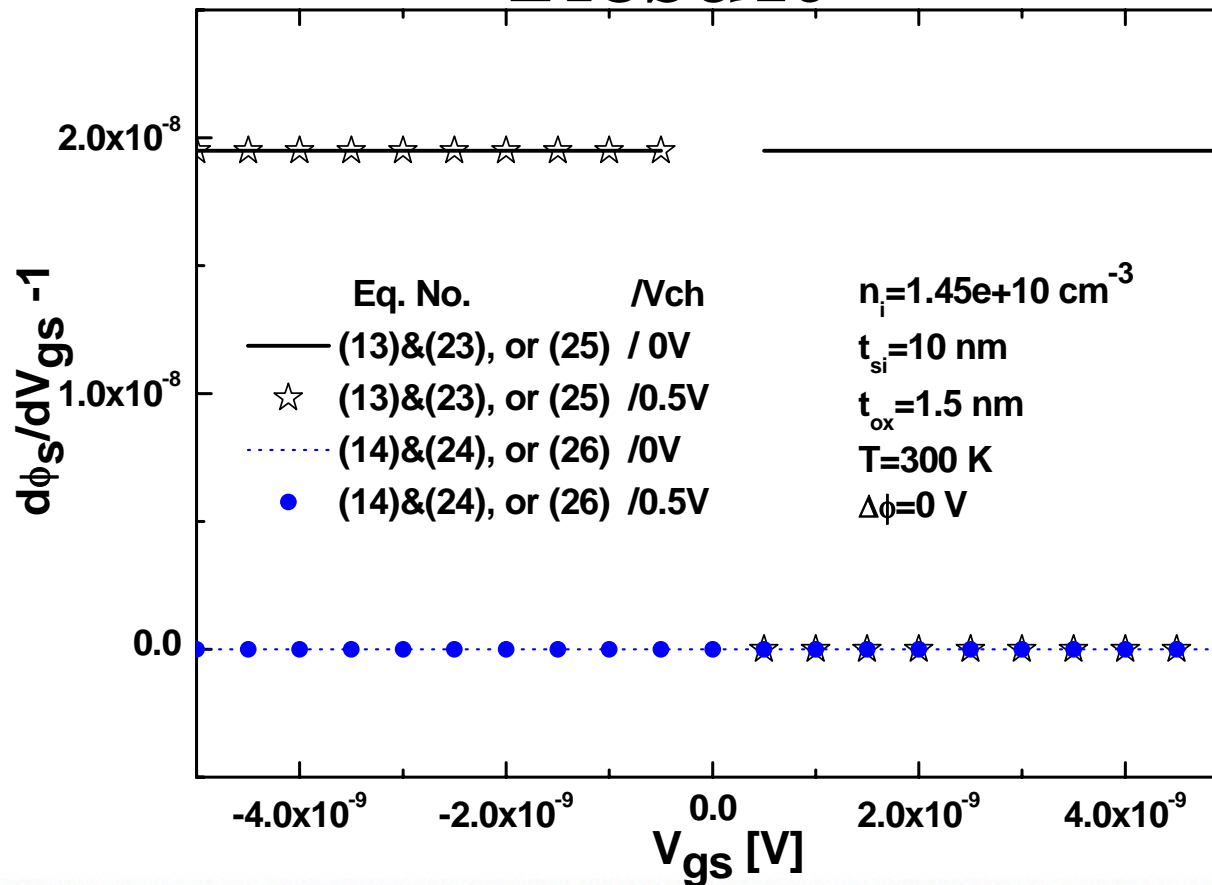


The comparison of ϕ_s versus V_{gs} of near flat band-point between three equation pairs for different V_{ch} , in a refined gate voltage region, showing a discontinuity of the surface potential from Eqs. (13) and (22) pairs.



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Result

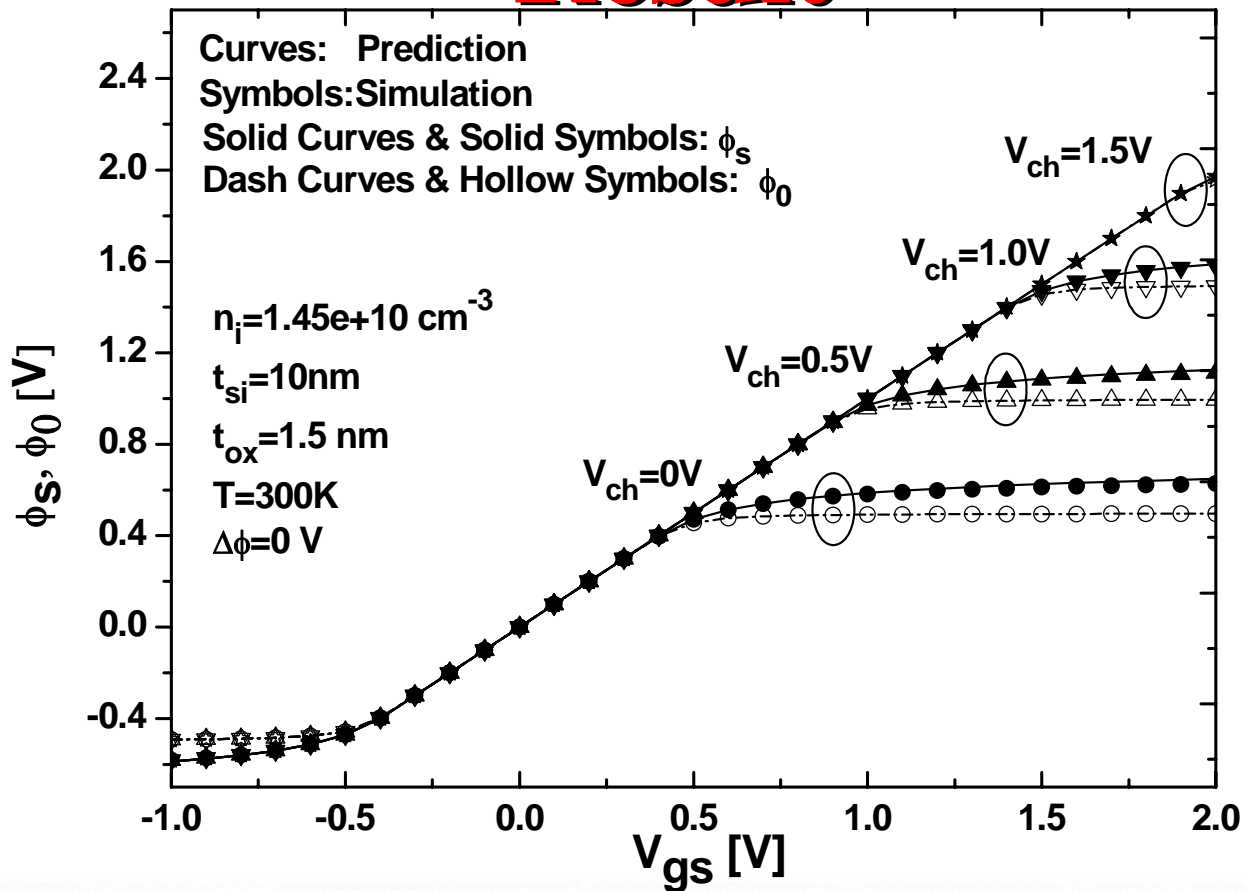


The comparison of $d\phi_s/dV_{gs}$ versus V_{gs} near the flat-band point between Eqs. (25) and (26), showing the discontinuity of surface potential derivative from Eq. (25) in a DG MOSFET.



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Result



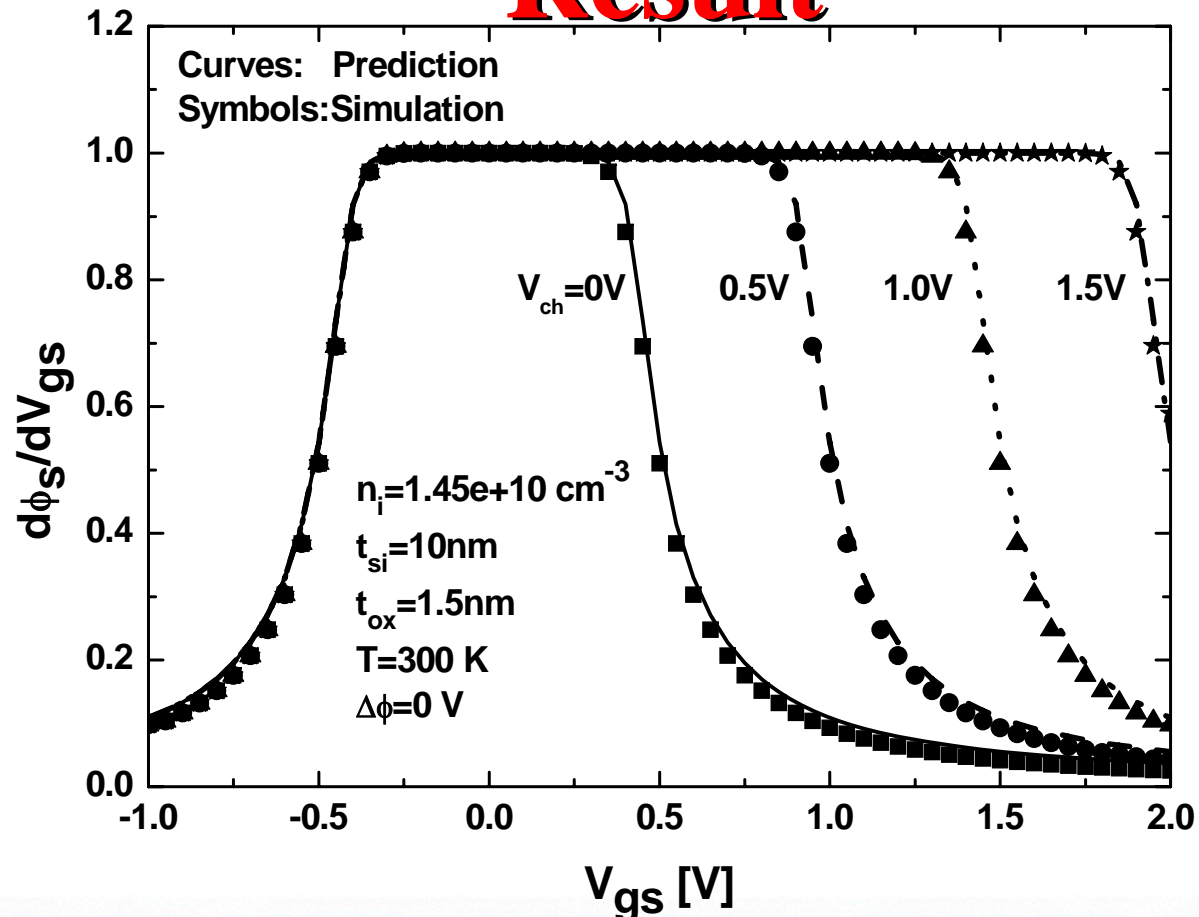
Comparison of ϕ_s and ϕ_0 versus V_{gs} between the 2-D simulation and surface potential equation prediction for different V_{ch} in a DG MOSFET.



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Result

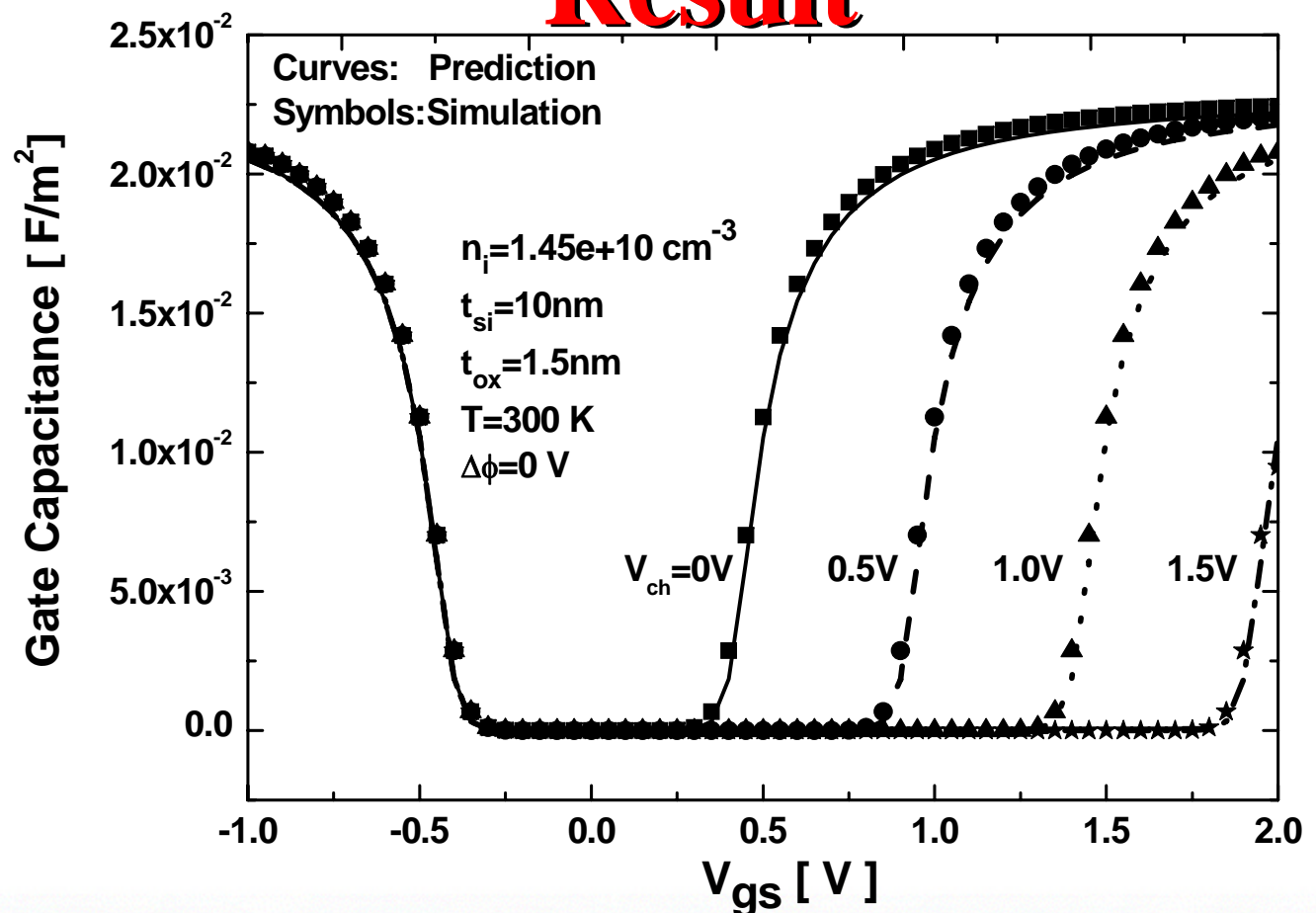


Comparison of the derivatives versus V_{gs} between the 2-D simulation and surface potential equation prediction for different V_{ch} in a DG MOSFET.



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Result

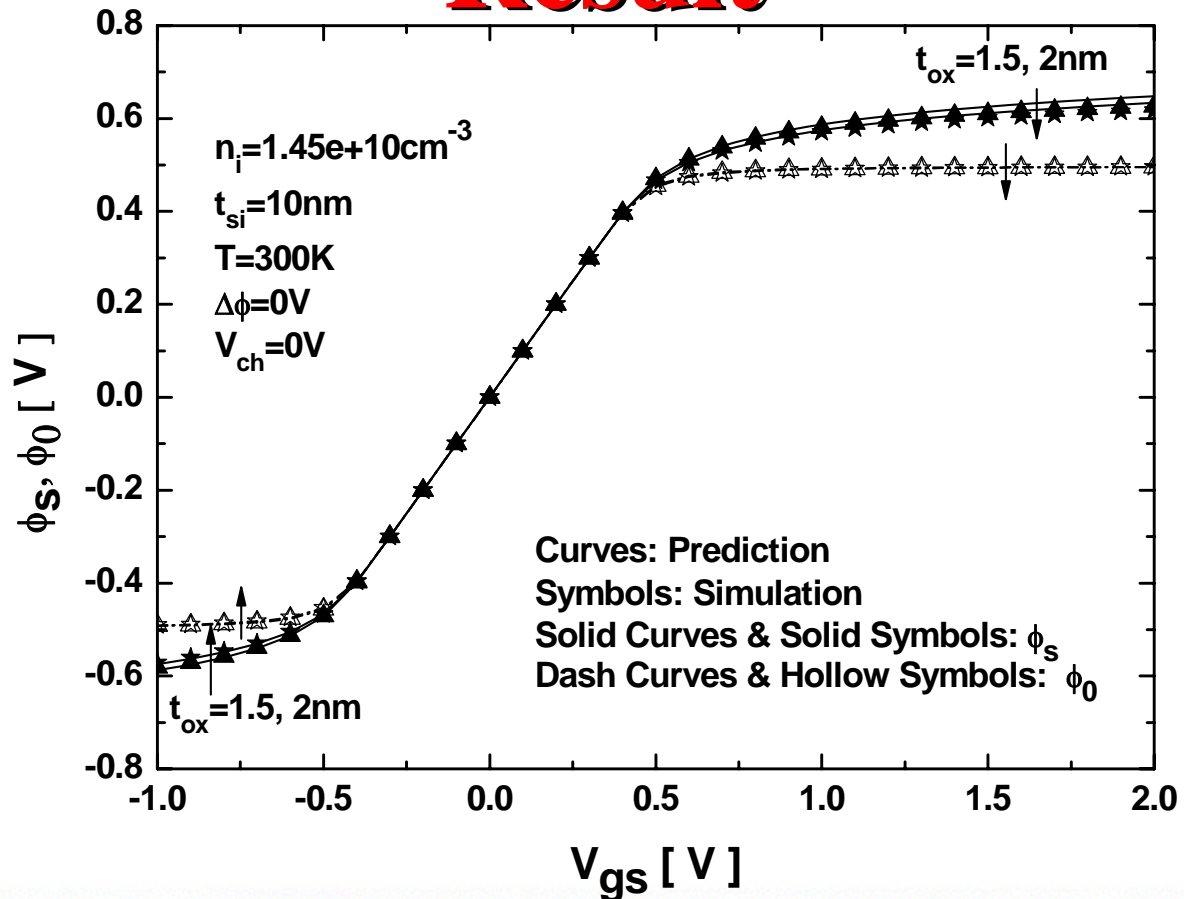


Comparison of the gate capacitance versus V_{gs} between the 2-D simulation and surface potential equation prediction for different V_{ch} in a DG MOSFET.



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Result

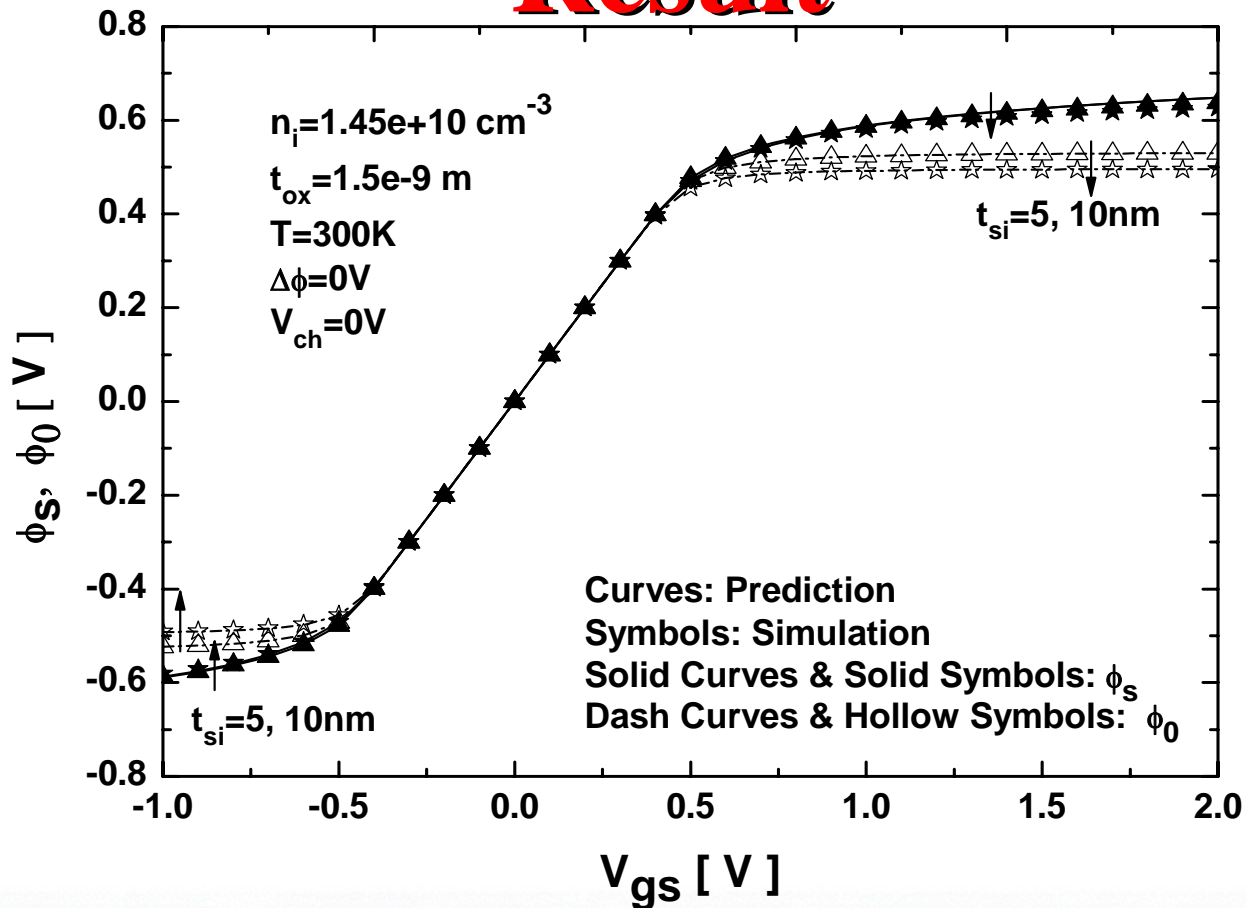


Comparison of ϕ_s and ϕ_0 versus V_{gs} between the 2-D simulation and surface potential equation prediction for different thickness of gate oxide in a DG MOSFET.



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Result

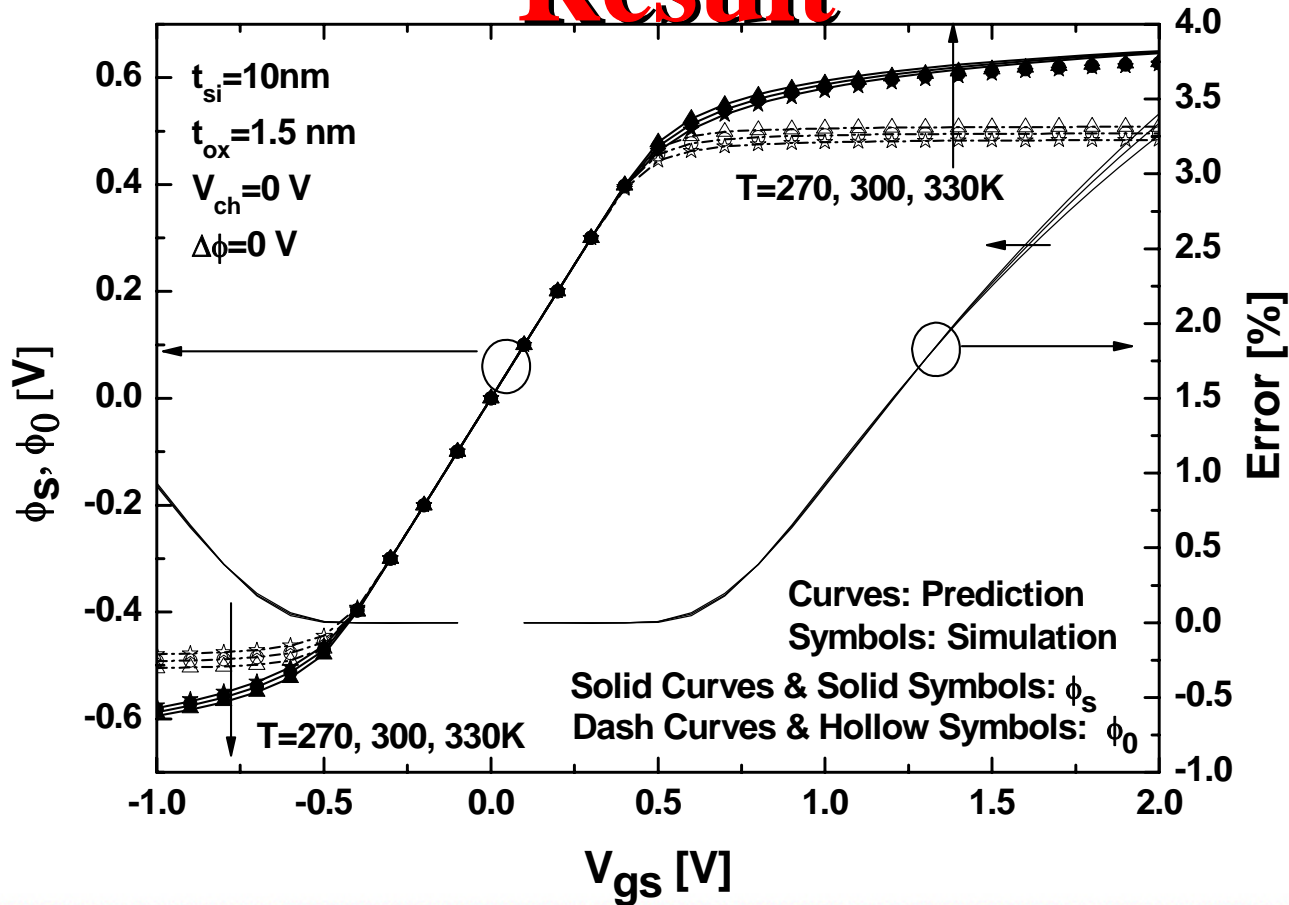


Comparison of ϕ_s and ϕ_0 versus V_{gs} between the 2-D simulation and surface potential equation prediction for different silicon film thickness in a DG MOSFET.



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Result

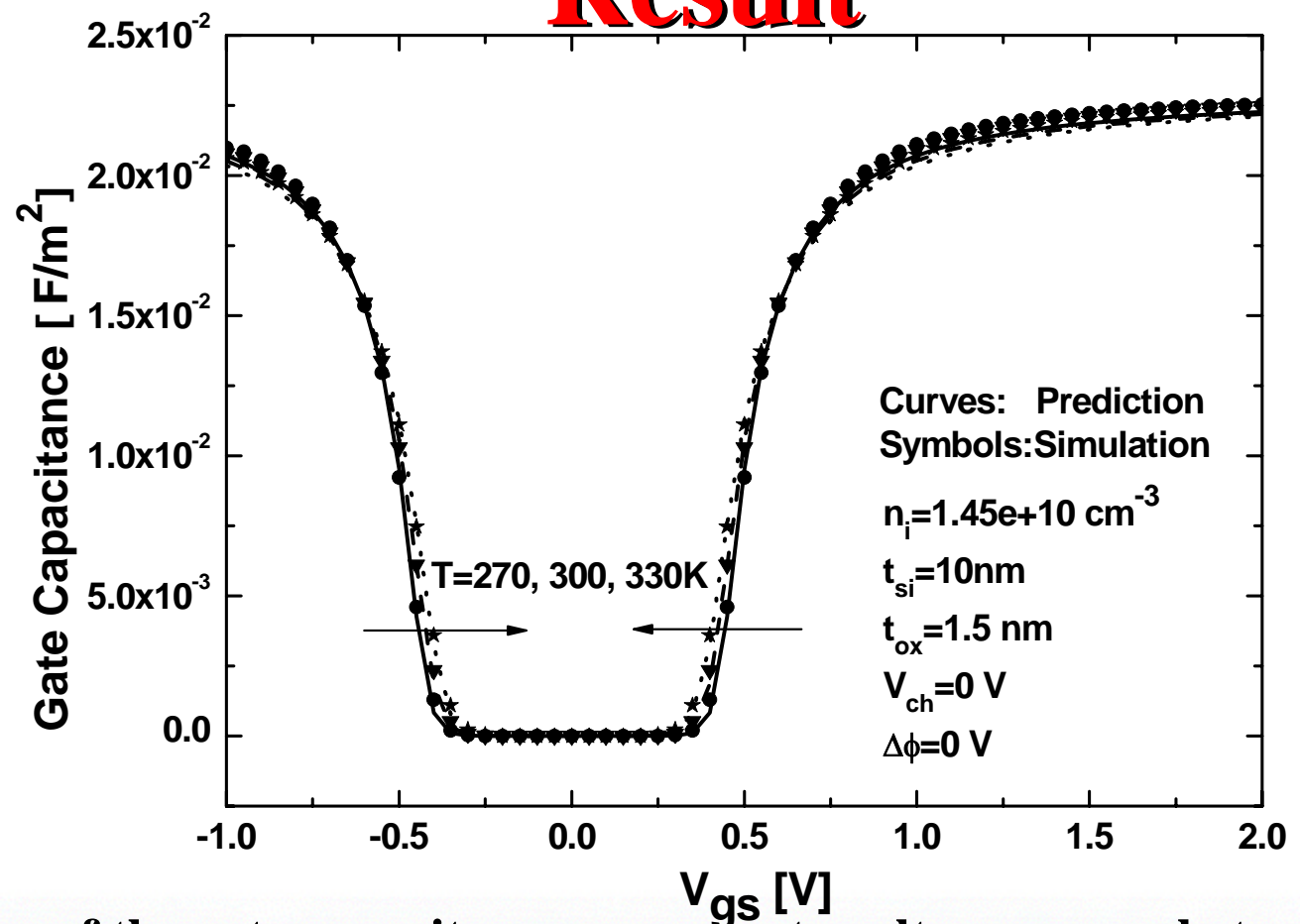


Comparison of ϕ_s and ϕ_0 versus V_{gs} between the 2-D simulation and surface potential equation and the resultant error of ϕ_s for different operation temperature in a DG MOSFET.



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Result



Comparison of the gate capacitance versus gate voltage curves between the 2-D simulation and surface potential equation prediction for different operation temperature in a DG MOSFET.



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