Unified Regional Surface Potential for Modeling Common-Gate Symmetric/Asymmetric Double-Gate MOSFETs with Quamtum Mechanical Effects

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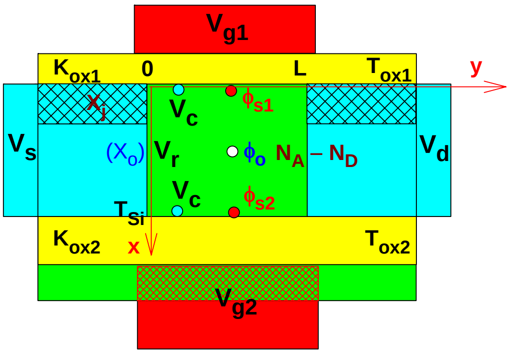
Outline

- **Common-Gate Double Gate MOSFETs**
- **Unified Regional Potential Solution**
- **Quantum Mechanical Correction**
- **Results & Discussion**
- **Conclusions**

The Generic Double-Gate Structure



Zero-field potential: ϕ_o [$\phi_o'(X_o) = 0$]

Imref split: $V_{cr} = \phi_{Fn} - \phi_{Fp}$

$V_{cr} = V_{cb}$ (bulk);
$V_{cr} = V_{cm}$ (DG), $V_m = \min(V_s, V_d)$

- **Common-gate DG**
  - $V_{g1} = V_{g2} = V_g$: two gates with one bias
  - $C_{ox1} = C_{ox2}$: **s-DG** ($X_o = T_{Si}/2$)
  - **Full-depletion**: $V_{FD} = V_g(X_d = T_{Si}/2)$
  - $C_{ox1} \neq C_{ox2}$: **ca-DG** ($X_o < T_{Si}$)
  - Depletion by individual gate (X_{d1} and X_{d2}) linked through **full-depletion** condition: $X_{d1} + X_{d2} = T_{Si}$
- **QME: due to quantum confinement of inversion charge**

Quantum Mechanical Correction

- van Dort's model

$$n_i^{qm} = n_i f^{qm} \qquad f^{qm} = \exp\left(-\Delta E_g^{qm} / v_{th}\right)$$

$$\Delta E_g^{qm} = \kappa \frac{3\hbar^2}{16qm^*}\left[\frac{12m^* q^2}{\varepsilon_{si}\hbar^2} F_s\right]^{2/3} \qquad F_s = \frac{2C_{ox}\left(V_{gs} - V_{FB} - \phi_s\right)/q}{3}$$

- Replace modified intrinsic carrier density into unified regional solution (accumulation and strong inversion)

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Quantum Mechanical Correction

❑ Voltage equation with QME

$$V_{gs} - V_{FB} - \phi_s^{qm} = -Q_{sc}^{qm} / C_{ox} \qquad Q_{sc}^{qm} = -C_{ox} \Upsilon \,\mathrm{sgn}\left(\phi_s^{qm}\right) \sqrt{f_\phi^{qm}}$$

$$f_\phi^{qm} = v_{th} \left[f^{qm} \exp\left(-\frac{\phi_s^{qm}}{v_{th}}\right) - \exp\left(-\frac{\phi_o}{v_{th}}\right) \right] + \left(\phi_s^{qm} - \phi_o\right) \left[1 - \exp\left(-\frac{V + 2\phi_F}{v_{th}}\right) \right]$$
$$+ v_{th} \exp\left(-\frac{V + 2\phi_F}{v_{th}}\right) \left[f^{qm} \exp\left(\frac{\phi_s^{qm}}{v_{th}}\right) - \exp\left(\frac{\phi_o}{v_{th}}\right) \right]$$

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Quantum Mechanical Correction

❑ Regional solutions with QME

- Hole only

$$\ln\left(\frac{V_{gsf}^2}{f^{qm}\gamma^2 v_{th}}\right) + \ln\left(1 - \frac{2\phi_s^{qm}}{V_{gsf}} + \frac{\left(\phi_s^{qm}\right)^2}{V_{gsf}^2}\right) = -\phi_s^{qm} / v_{th}$$

- Electron only

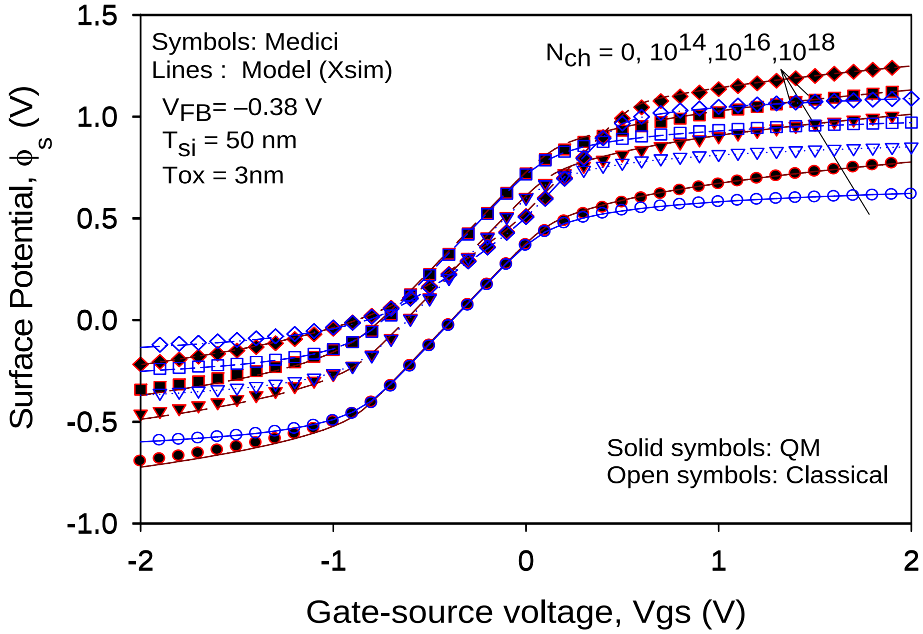
$$\ln\left(\frac{V_{gsf}^2}{f^{qm}\gamma^2 v_{th}}\right) + \ln\left(1 - \frac{2\phi_s^{qm}}{V_{gsf}} + \frac{\left(\phi_s^{qm}\right)^2}{V_{gsf}^2}\right) = \left(\phi_s^{qm} - 2\phi_F - V\right) / v_{th}$$

$$\boxed{\left(\phi_s^{qm}\right)^3 + p\left(\phi_s^{qm}\right)^2 + q\left(\phi_s^{qm}\right) + r = 0}$$

$$\phi_s^{qm} = \begin{cases} \phi_{cc}^{qm}, & V_{gb} < V_{FB} \\ \phi_{ss}^{qm}, & V_{gb} > V_t \end{cases}$$

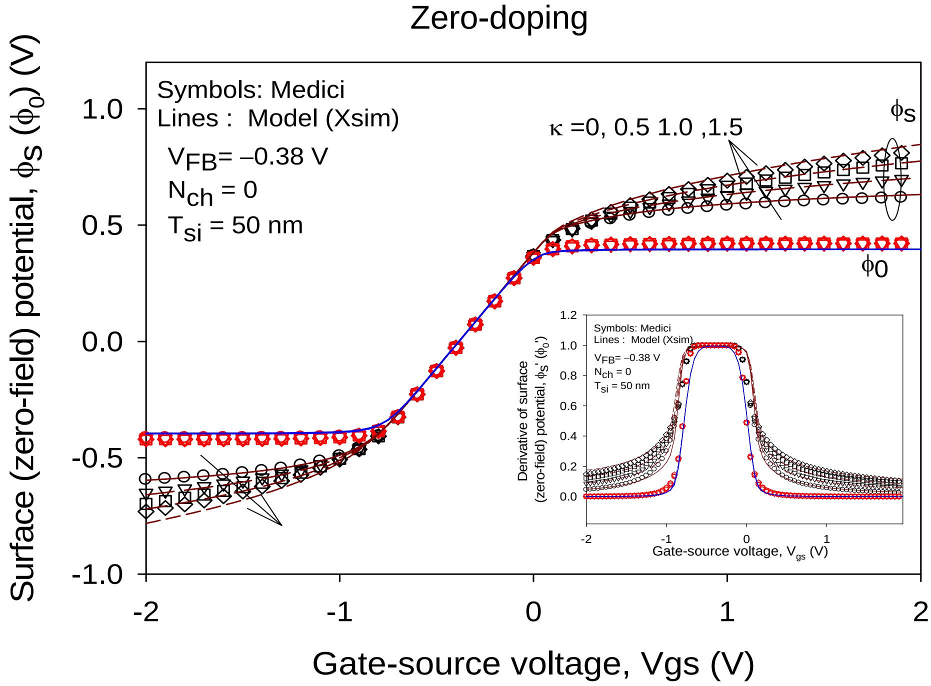
Results and Discussion

Body doping variation



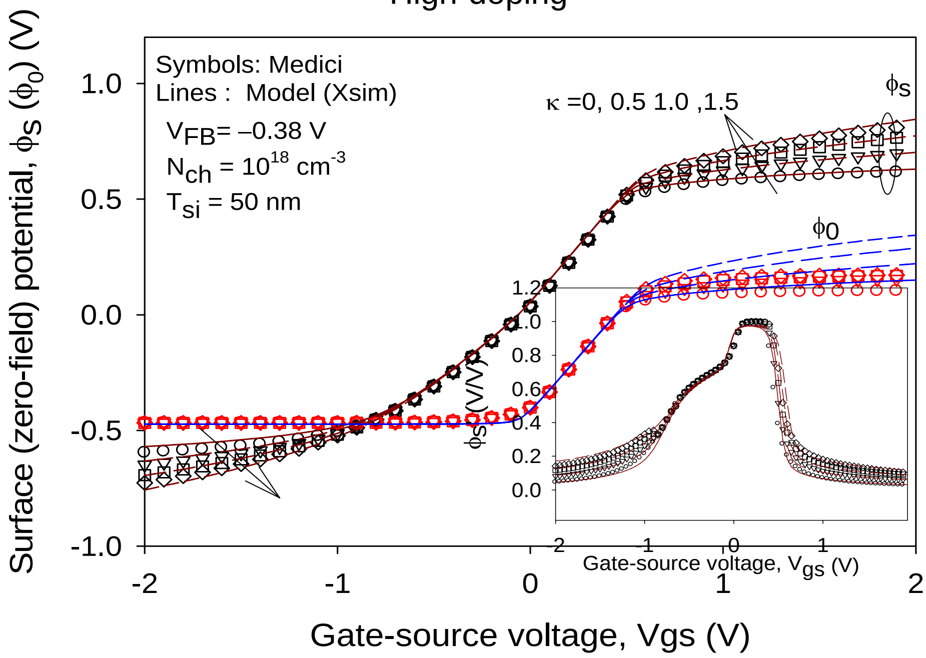
Results and Discussion

Zero-doping



Results and Discussion

High-doping



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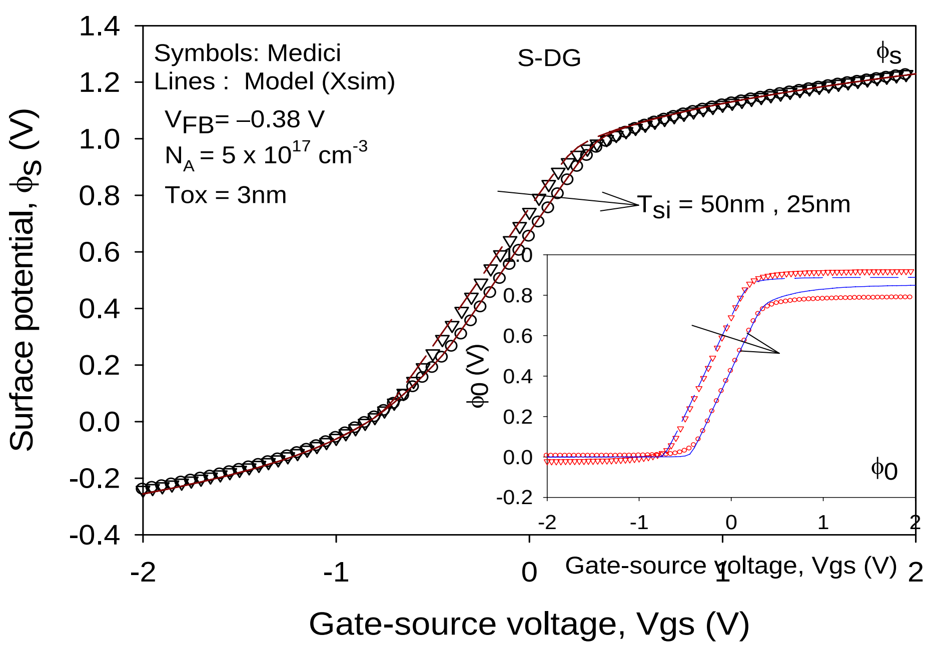
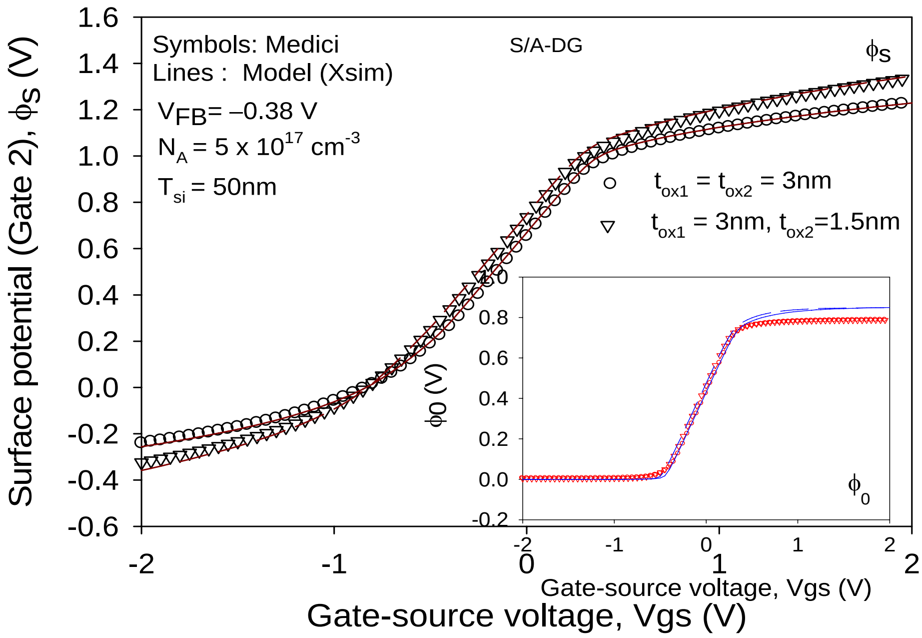
Results and Discussion

Body thickness variation



Results and Discussion



Conclusions

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- ❑ **Ca-DG potential model including QME is physically derived**
- ❑ **The transition from partially-depleted to fully-depleted operation with QME is seamlessly built into the model**
- ❑ **Terminal current can be obtained based on the potential solution**