Reducing Electrostatic Screening in Field-Effect-Transistor-Based (FET-based) Biosensors

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Annual Research Review
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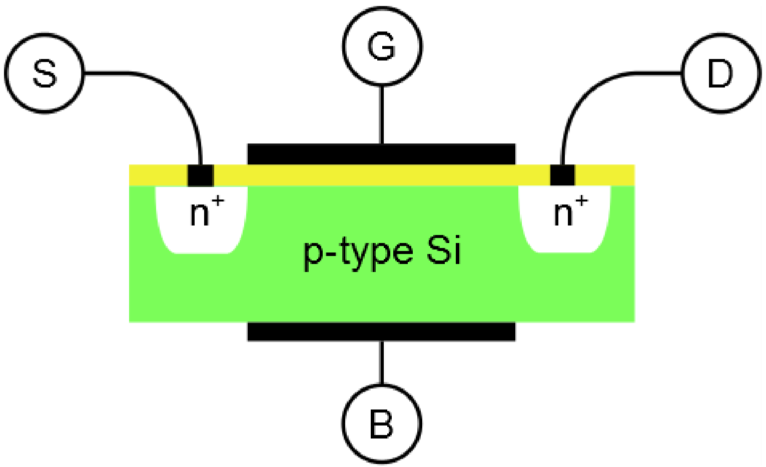
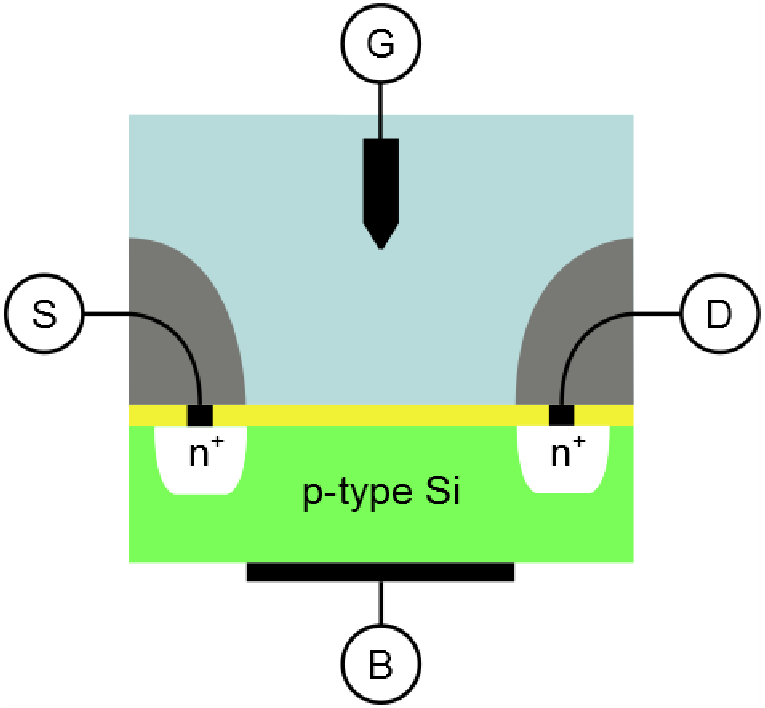
Ion Sensitive Field-Effect Transistor (ISFET)

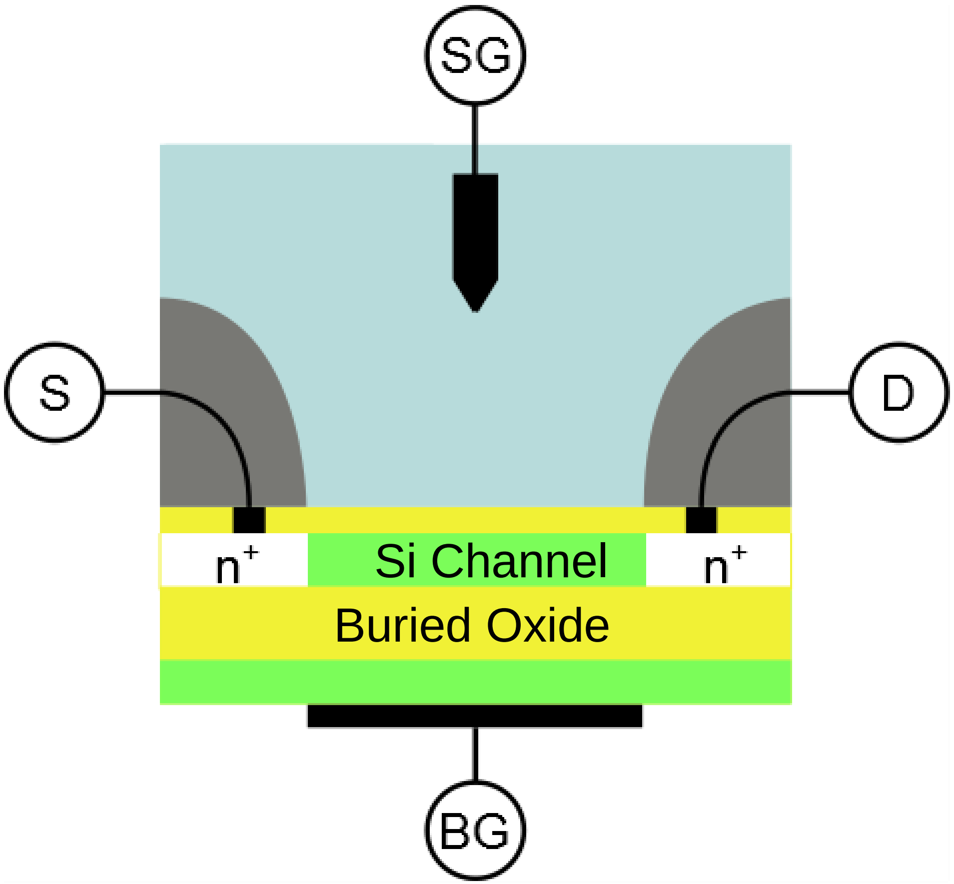


MOSFET

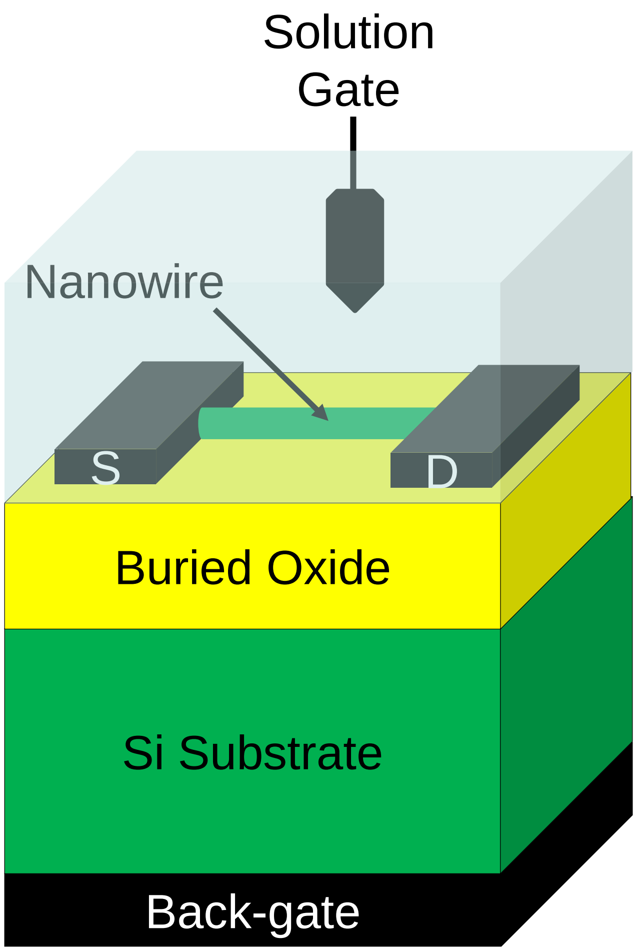


ISFET

Non-Planar Channel FET Biosensors

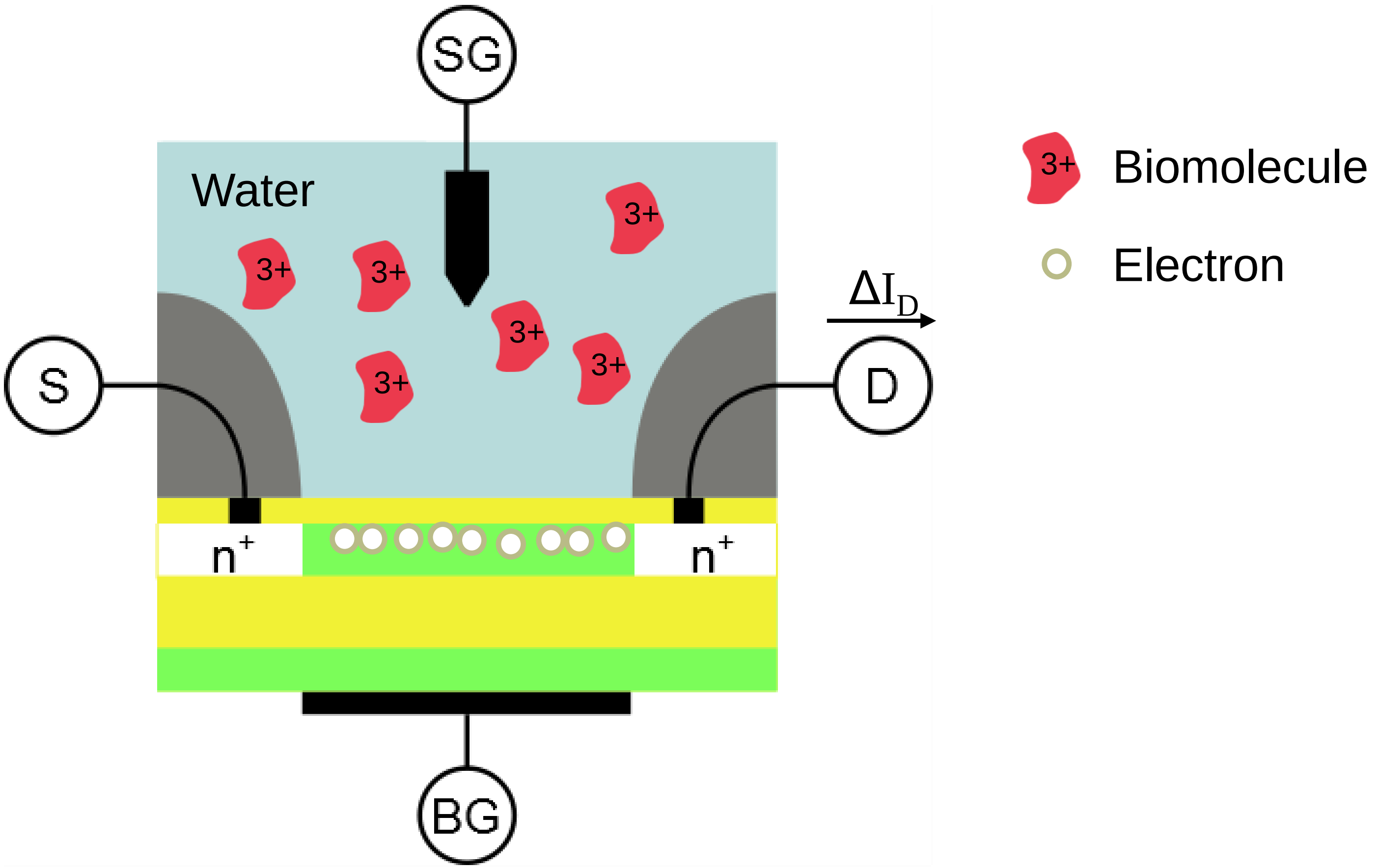


Silicon-on-Insulator Biosensors



Nanowire Biosensors

Biosensor Operation in Water



Biosensor Operation in Electrolyte

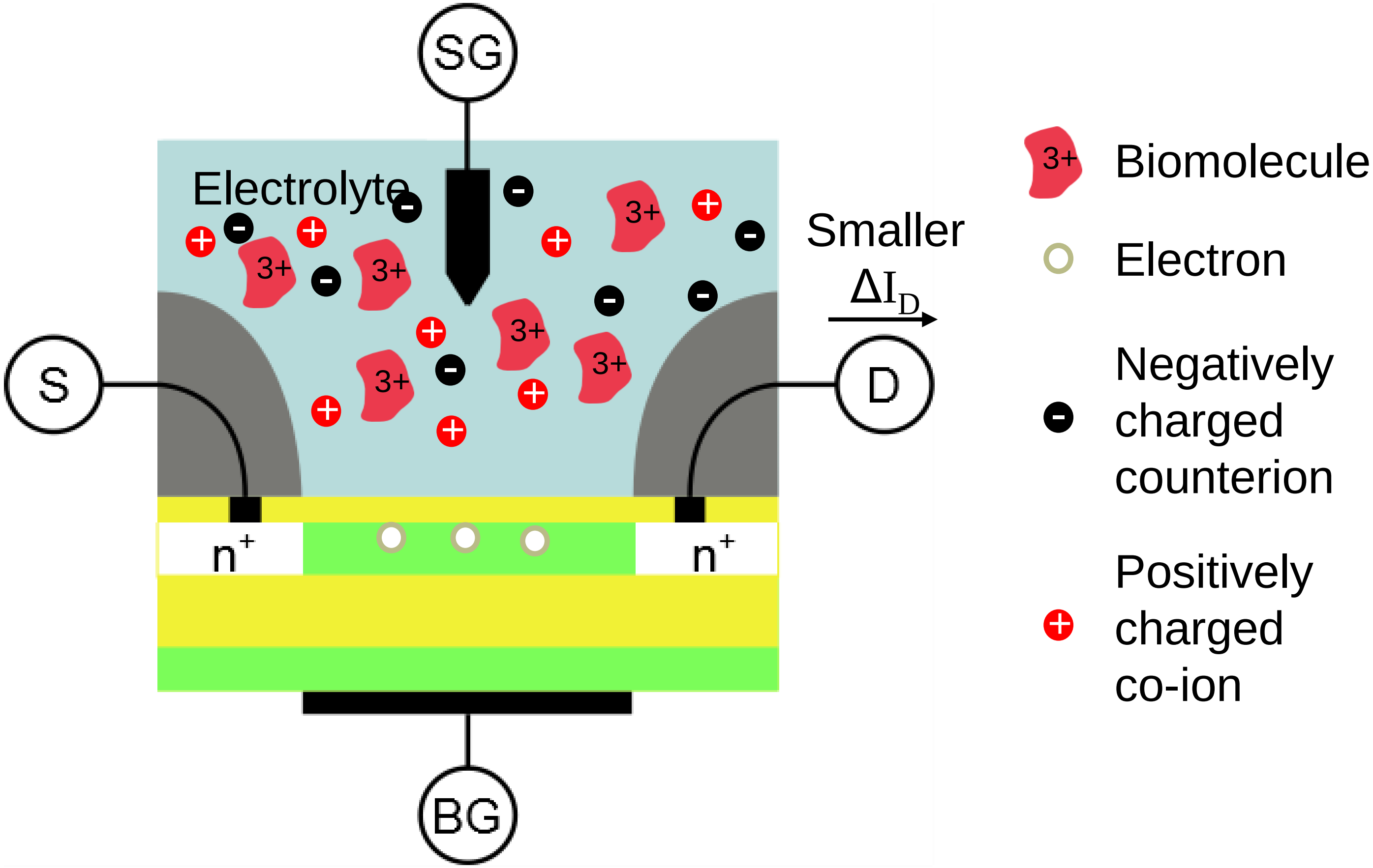
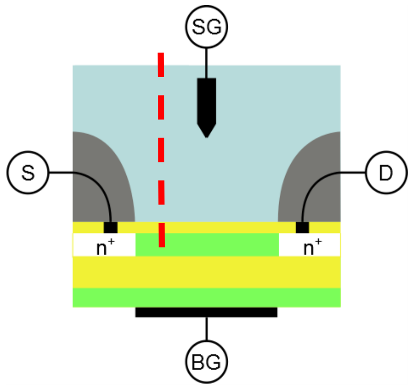
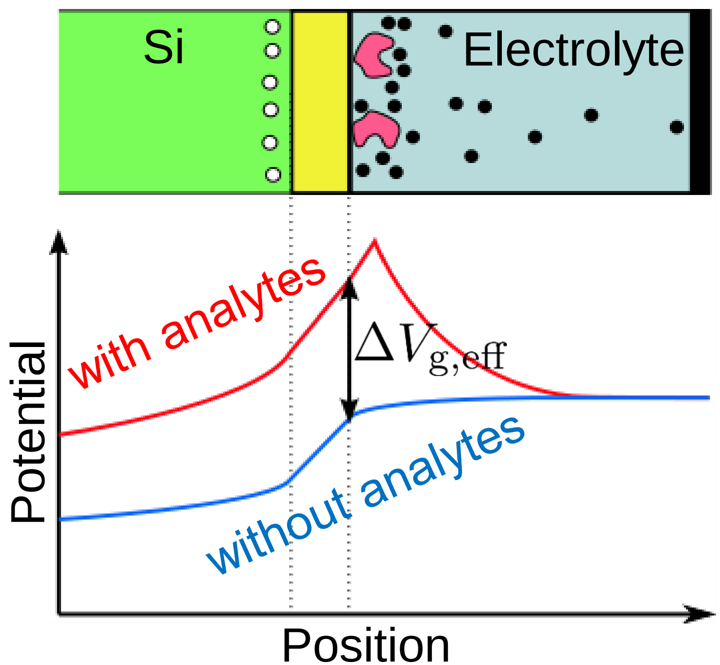
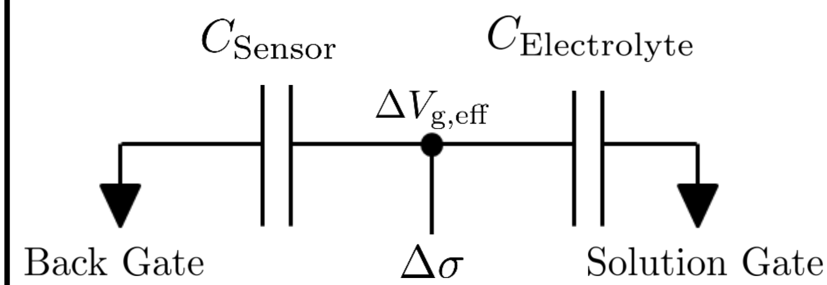


Figure of Merit: $\Delta I / I_0$





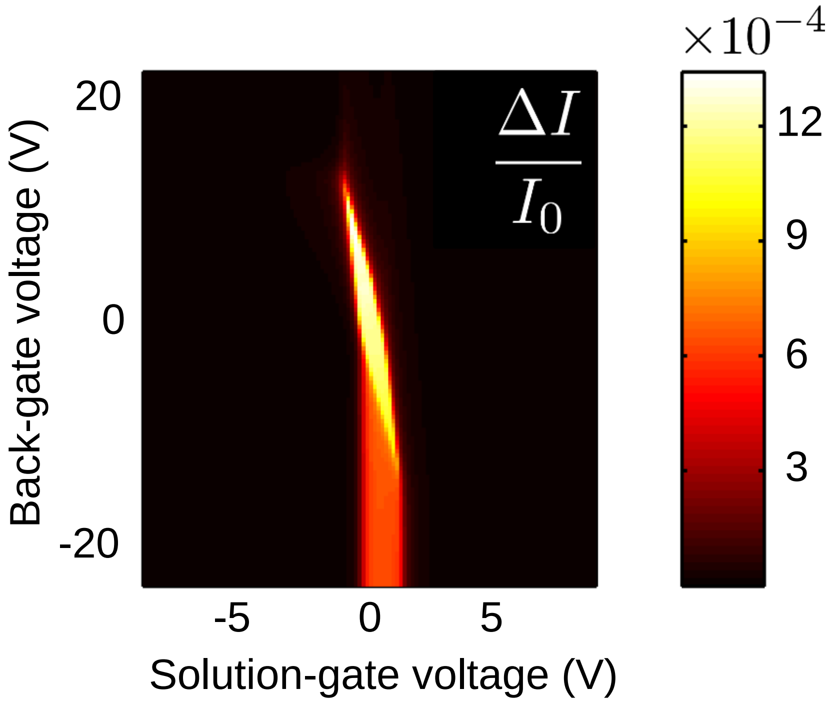


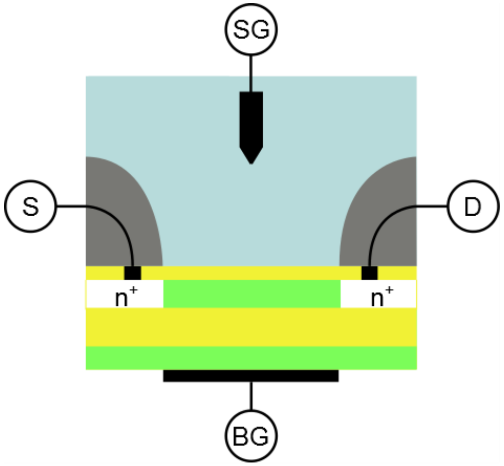
$$\frac{\Delta I}{I_0} = \Delta\sigma \, \frac{d(\Delta V_{\mathrm{g,eff}})}{d(\Delta\sigma)} \, \frac{\frac{d(\Delta I)}{d(\Delta V_{\mathrm{g,eff}})}}{I_0}$$

$$\frac{\frac{d(\Delta I)}{d(\Delta V_{\mathrm{g,eff}})}}{I_0} = \frac{g_{\mathrm{m}}}{I_{\mathrm{D}}}$$

Sensitivity is a Function of Biasing Point

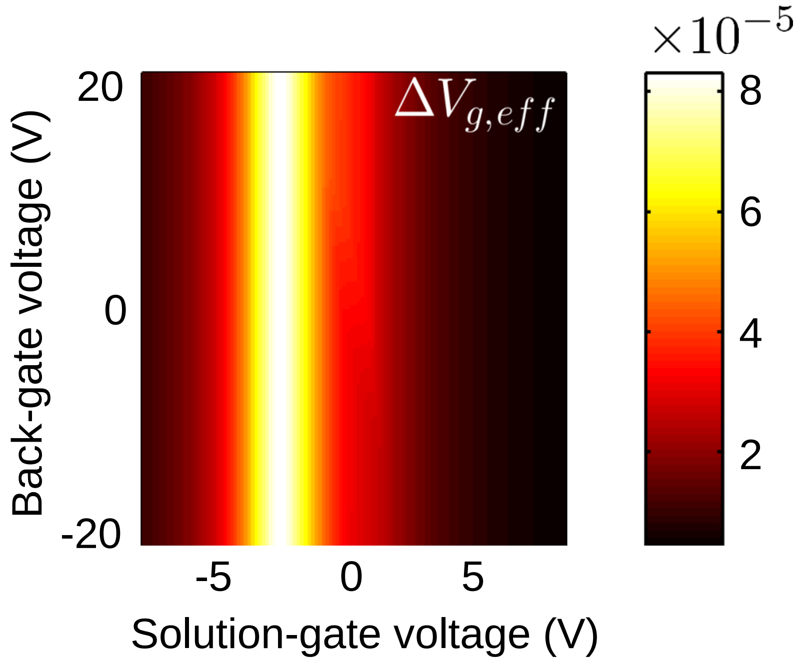
$$\frac{\Delta I}{I_0} = \Delta\sigma \frac{d(\Delta V_{g,\mathrm{eff}})}{d(\Delta\sigma)} \frac{\frac{d(\Delta I)}{d(\Delta V_{g,\mathrm{eff}})}}{I_0}$$

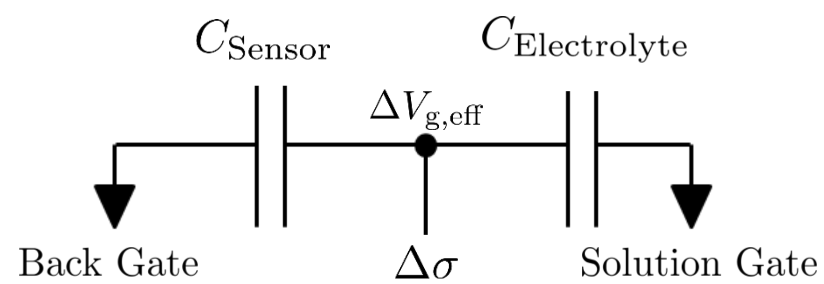




Bias Dependence of $\Delta V_{\mathrm{g,eff}}$

$$\frac{\Delta I}{I_0} = \Delta\sigma \, \frac{\mathrm{d}(\Delta V_{\mathrm{g,eff}})}{\mathrm{d}(\Delta\sigma)} \, \frac{\frac{\mathrm{d}(\Delta I)}{\mathrm{d}(\Delta V_{\mathrm{g,eff}})}}{I_0}$$





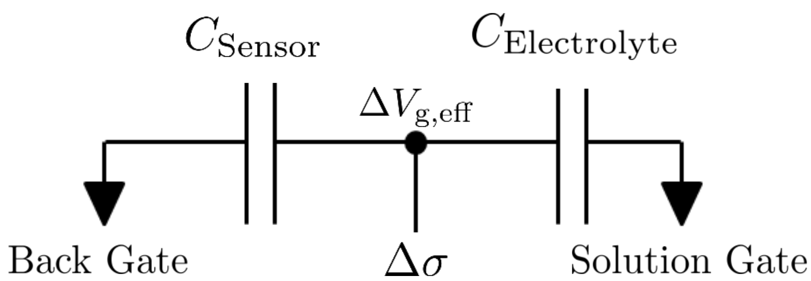
$$\Delta V_{\mathrm{g,eff}} = \frac{\Delta\sigma}{C_{\mathrm{Electrolyte}} + C_{\mathrm{Sensor}}}$$

Electrolyte Capacitance is Dominant

- **Capacitance in Solution:**
  - Solution with 100mM ionic strength:

$$C_{\mathrm{Electrolyte}} = \frac{80\epsilon_0}{\lambda_{\mathrm{Debye}}} = \frac{80\epsilon_0}{1\mathrm{nm}} \qquad \lambda_{\mathrm{Debye}} \equiv \sqrt{\frac{\epsilon_{\mathrm{w}}\epsilon_0 kT}{q^2\left(c_+ + c_-\right)}}$$

$$\approx \mathbf{70}\,\frac{\boldsymbol{\mu}\mathbf{F}}{\mathbf{cm^2}}$$



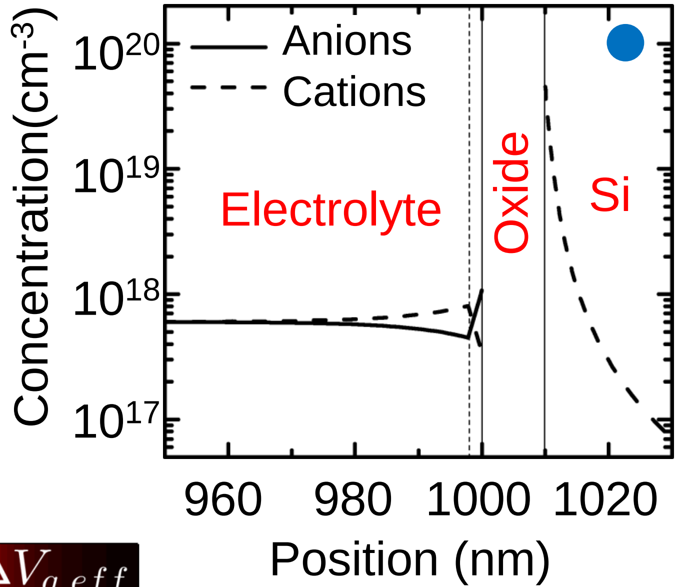
- **Capacitances in Sensor**
  - 20nm SOI Layer:

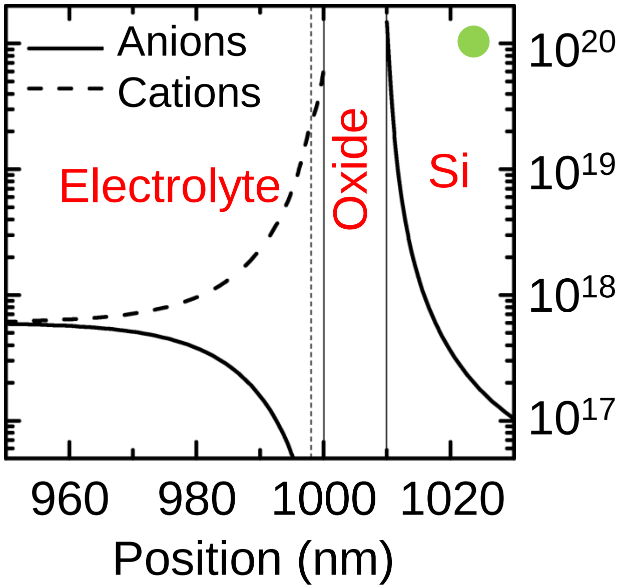
$$C_{\mathrm{Si}} = \frac{11.7\epsilon_0}{20\mathrm{nm}} \approx \mathbf{0.5}\,\frac{\boldsymbol{\mu}\mathbf{F}}{\mathbf{cm^2}}$$

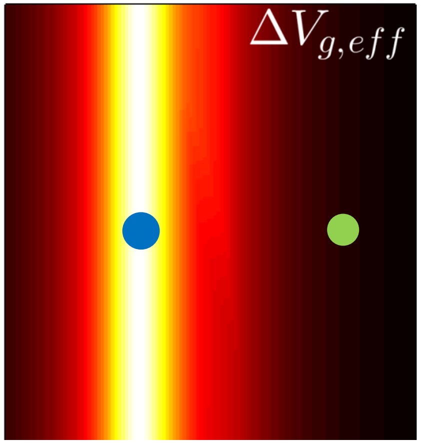
  - 1nm Native Oxide on Silicon:

$$C_{\mathrm{ox}} = \frac{3.9\epsilon_0}{1\mathrm{nm}} \approx \mathbf{3.5}\,\frac{\boldsymbol{\mu}\mathbf{F}}{\mathbf{cm^2}}$$

Ion Concentration and $\Delta V_{\mathrm{g,eff}}$





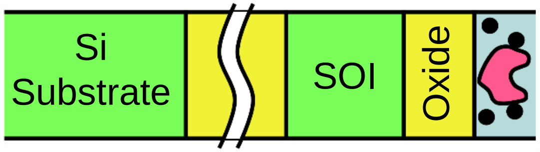


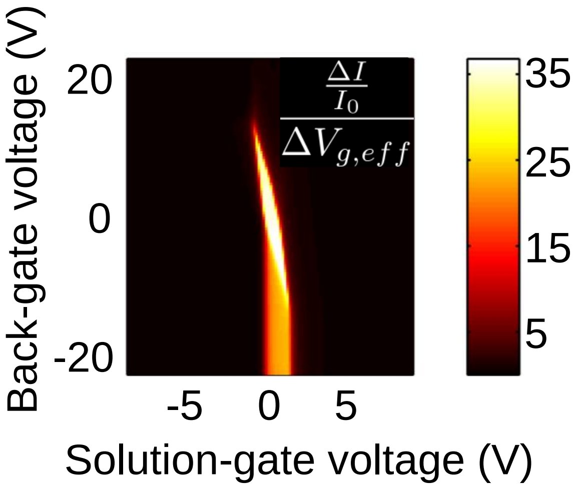
Biased where $\Delta V_{\mathrm{g,eff}}$ peaks, $\Delta V_{\mathrm{g,eff}} = 80\mu\mathrm{V}$

Biased in strong accumulation, $\Delta V_{\mathrm{g,eff}} = 8\mu\mathrm{V}$

Optimizing FET Action

$$\frac{\Delta I}{I_0} = \Delta\sigma \, \frac{d(\Delta V_{g,\mathrm{eff}})}{d(\Delta\sigma)} \, \frac{\frac{d(\Delta I)}{d(\Delta V_{g,\mathrm{eff}})}}{I_0}$$





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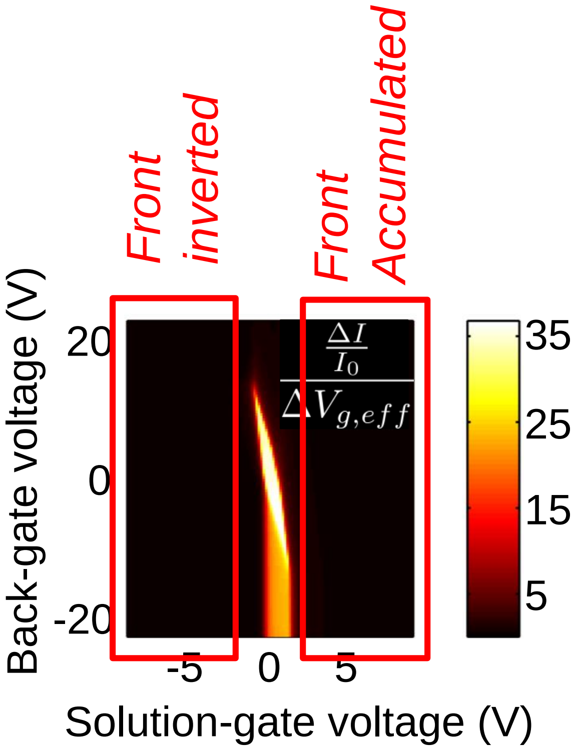

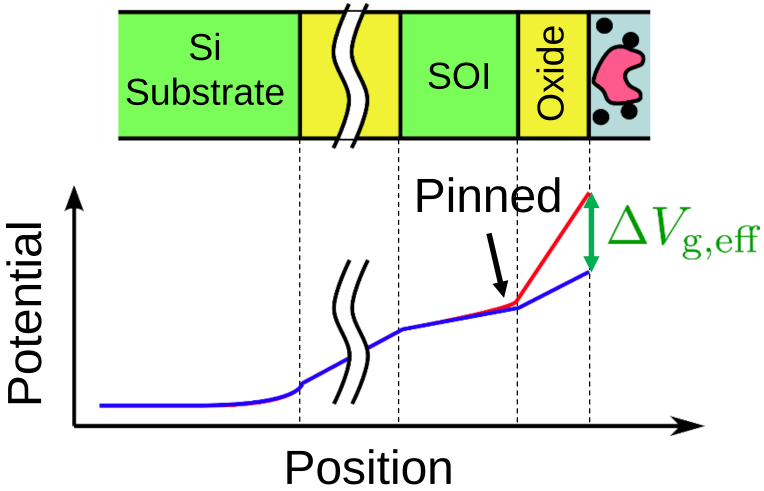

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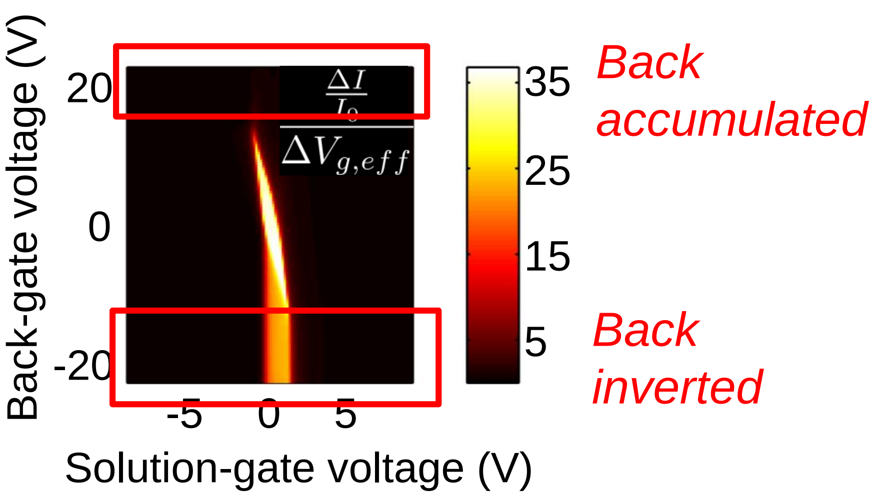

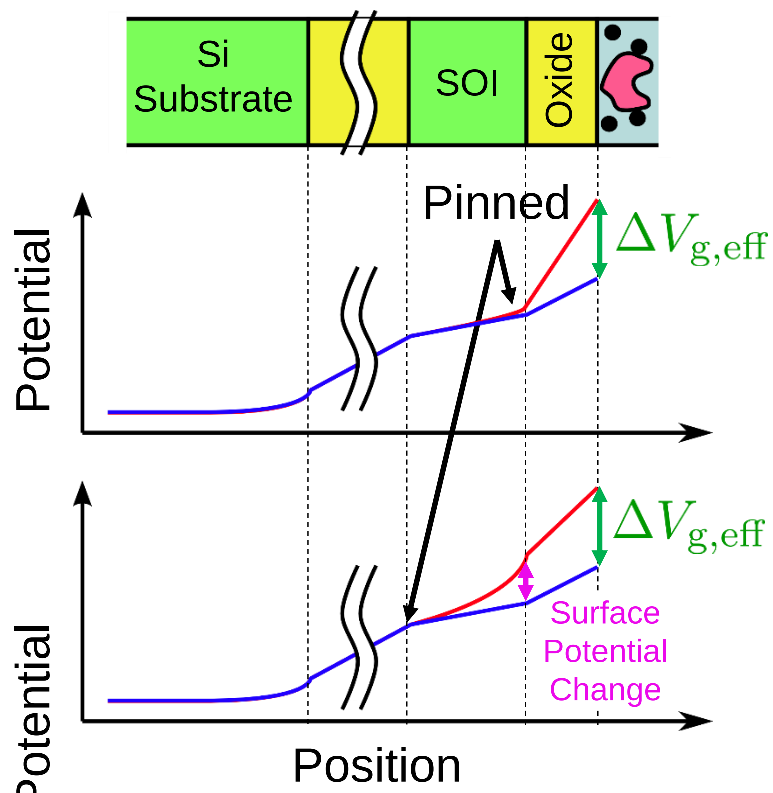

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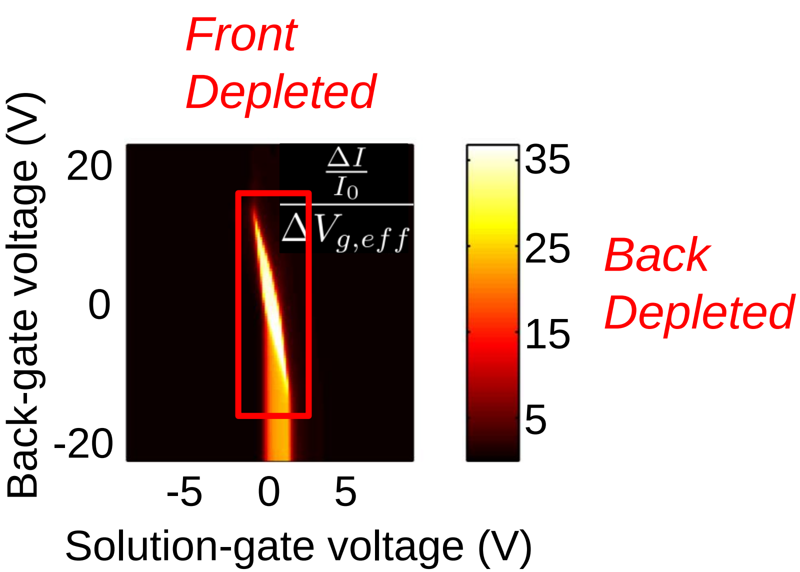
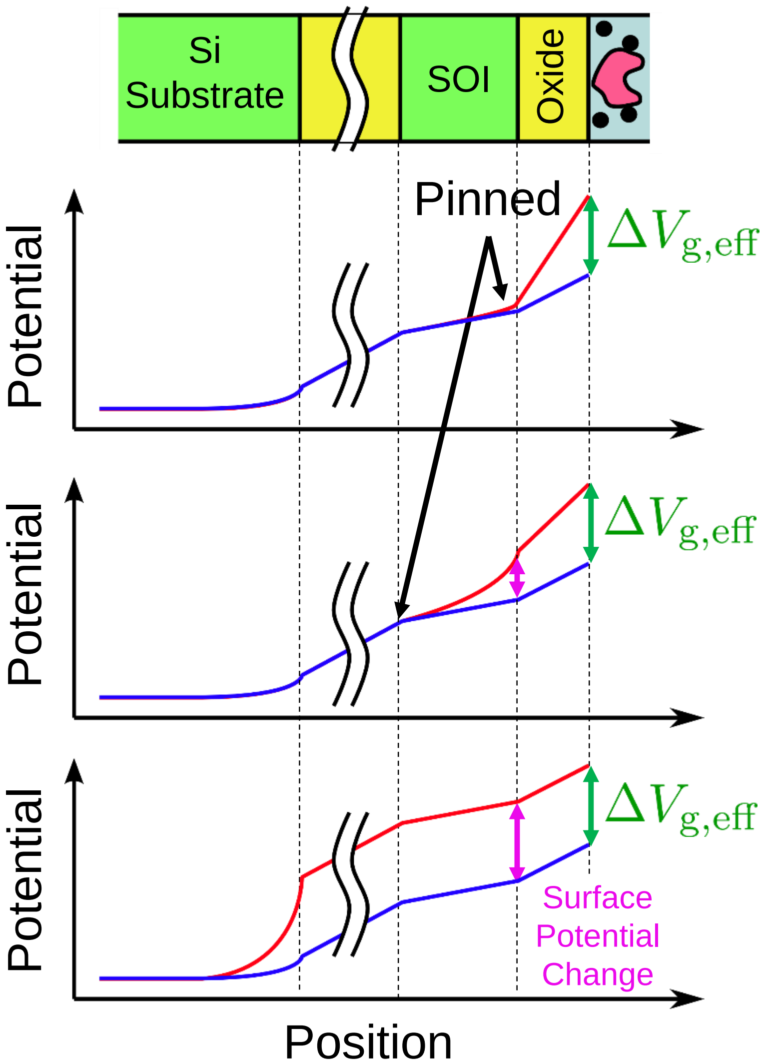
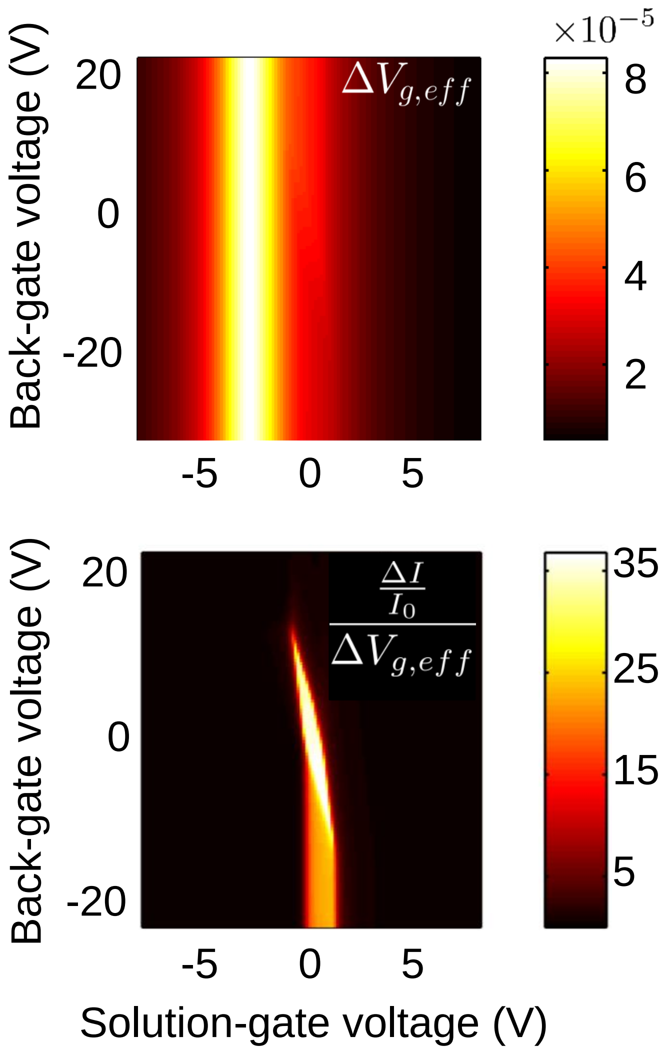




Maxima Do Not Coincide



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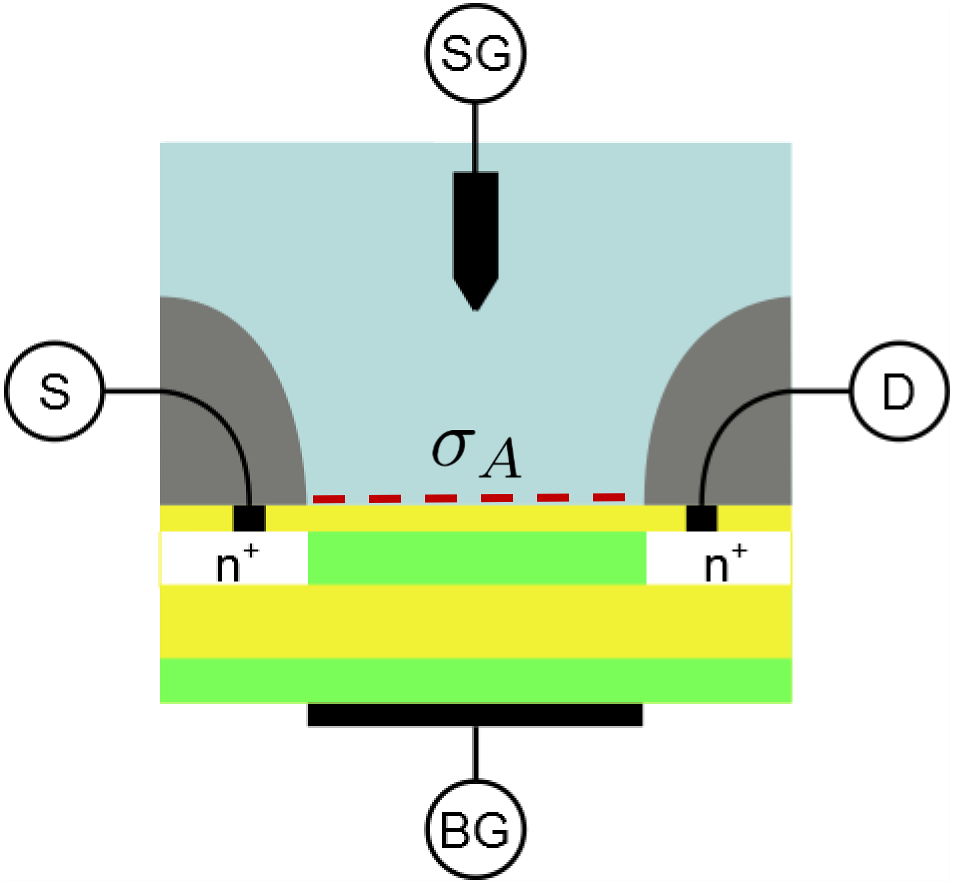
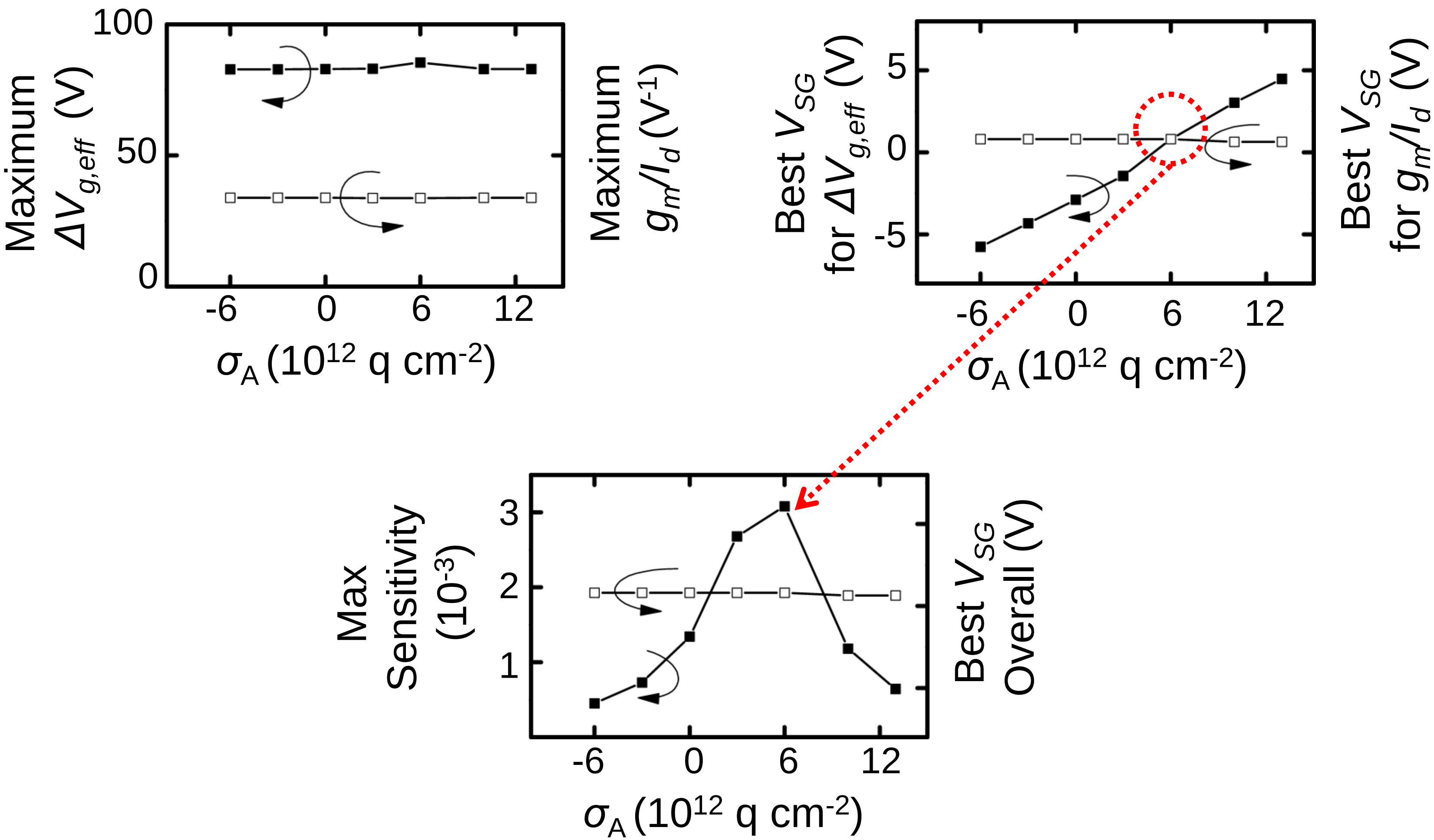
Adding "Adjustment Charges"



Adjustment charges could come from:

- Charged surface groups
- Dipoles between surface layers
- Charged receptors
- Charged linkers

Varying Adjustment Charge Density σ_A



Conclusions

- **Biasing matters (a lot!)**
  - **Bias in region of steepest slope**
- **Screening matters**
  - **Minimize surface electric field**
- **Surface charge engineering can help**

- **Shoorideh, K., Chui, C.O., *Electron Devices, IEEE Transactions on*, vol.59, no.11, pp. 3104-3110, Nov. 2012**

Thank You For Your Attention

Questions?