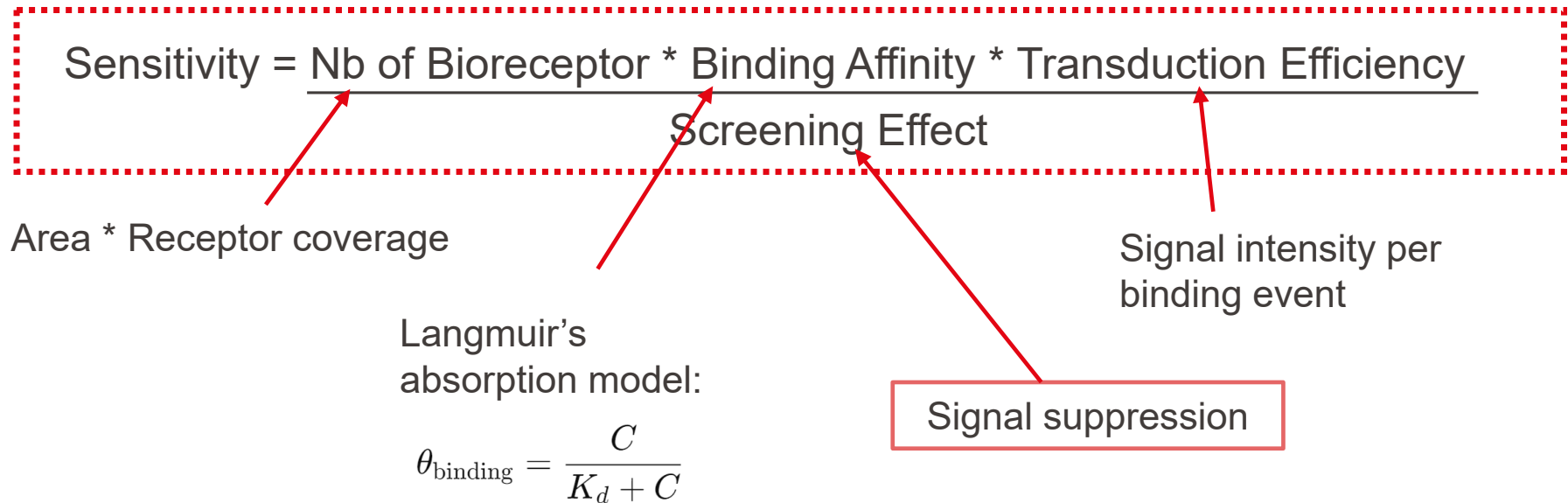


Nano Part II: Reducing signal suppression of Nanomaterial biosensor

Recap: Sensitivity

Definition

$$S = \frac{\Delta Y}{\Delta C} \quad \begin{array}{l} \text{Difference of Signal Intensity} \\ \text{Difference of Analyte Concentration} \end{array}$$



Origin of Screening effects

Classifications

1. Chemical

- | | |
|---|---|
| • pH changes | Electrochemical, Optical, Piezoelectric, mechanical |
| • High ionic strength/ salt effects | Electrochemical (esp. FETs), Optical (with charged label) |
| • Redox interference/ competing electroactive species | Electrochemical (amperometric/ voltammetric) |
| • Heavy metal/oxidants | Electrochemical, Enzymatic |

2. Physical

- | | |
|--|---|
| • Mass transport limitation | Electrochemical, Piezoelectric (surface sensors),
Magnetic (label transport) |
| • Temperature fluctuation | Electrochemical, Piezoelectric, Calorimetric, Mechanical |
| • Photobleaching/ light scattering | Optical (fluorescence) |
| • Nanoparticle aggregation | Optical (plasmonic assays), Magnetic |
| • Mechanical damping | Electrochemical, Piezoelectric, Mechanical, Magnetic |
| • Crowding/ Hindering/ Bad orientation | Electrochemical, Piezoelectric, Mechanical, Magnetic |

Origin of Screening effects

Classifications

3. Biological

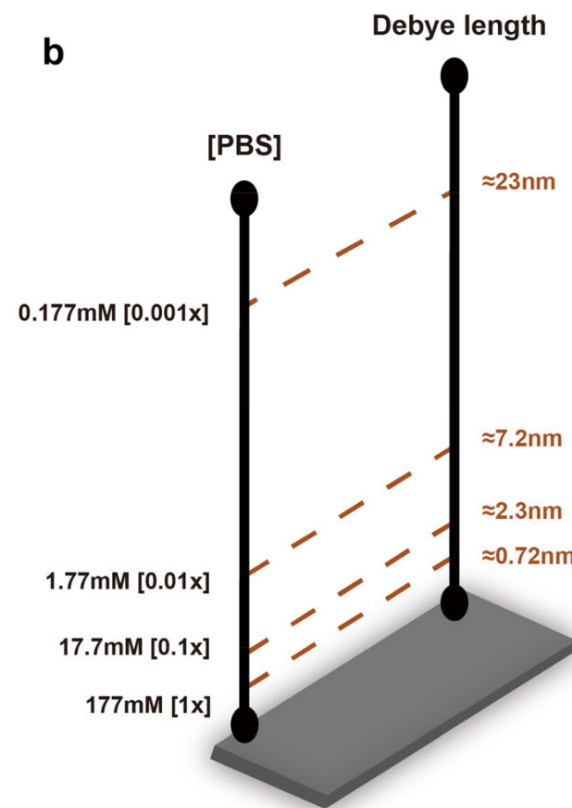
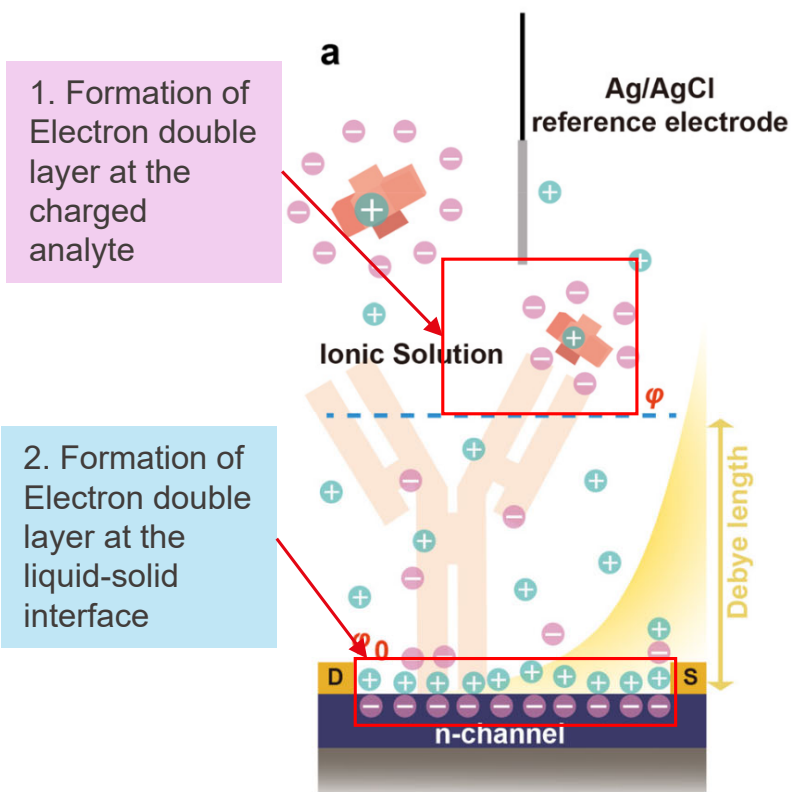
- | | |
|--|---|
| • Enzyme inhibition/ denaturation | Electrochemical (enzymatic), Calorimetric |
| • Non-specific binding | Electrochemical, Optical, Piezoelectric, Magnetic, Mechanical |
| • Proteolytic degradation | Optical, Electrochemical, Mechanical |
| • Conformational loss on immobilization (orientation issues) | Electrochemical, Optical |

4. Mixed

- | | |
|-----------|-----------------|
| • Fouling | All transducers |
|-----------|-----------------|

Debye's length

Ionic strength screening



Debye Length:

$$\lambda_D = \sqrt{\frac{\epsilon_0 \epsilon_r K_B T}{2 N_A e^2 I}}$$

Ionic strength:

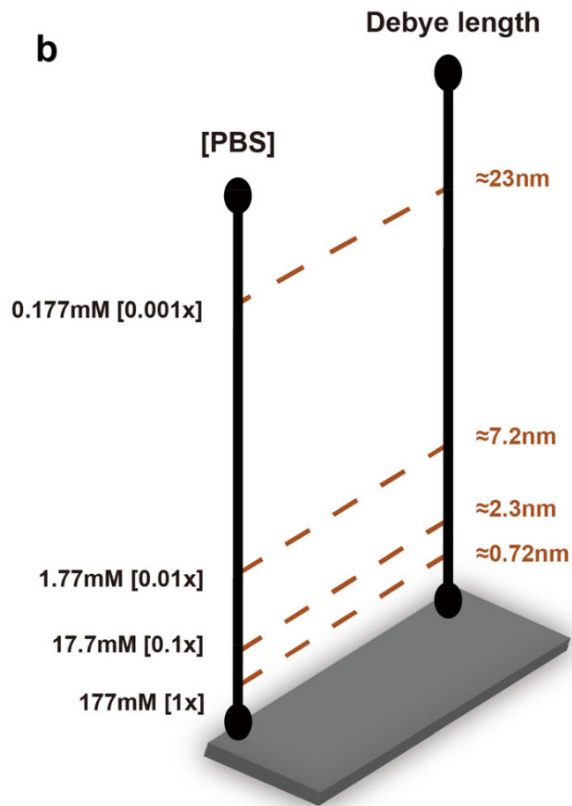
$$I = \frac{1}{2} \sum c_i z_i^2$$

Larger Debye length, less screening!!!

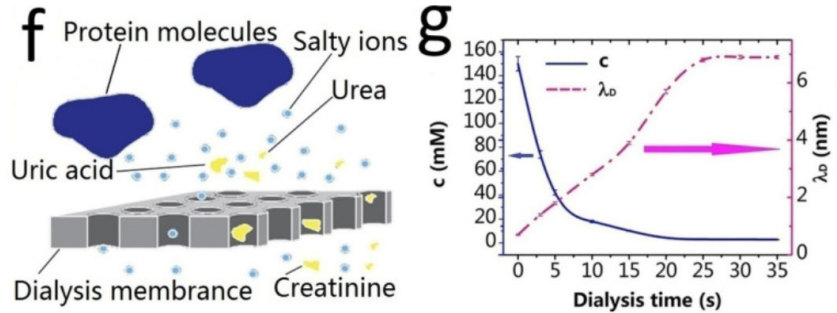
[1] Meng, Q. et al. Overcoming Debye screening effect in field-effect transistors for enhanced biomarker detection sensitivity. *Nanoscale* 16, 20864–20884 (2024).

Overcoming Debye length screening

Example 1: Lowering the ionic strength



Diluting the physiological sample to have less ion in the liquid. Normally 0.1mM PBS



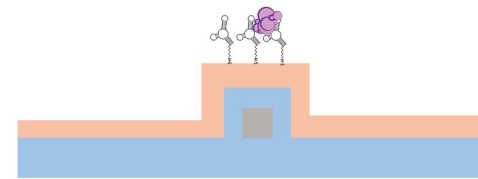
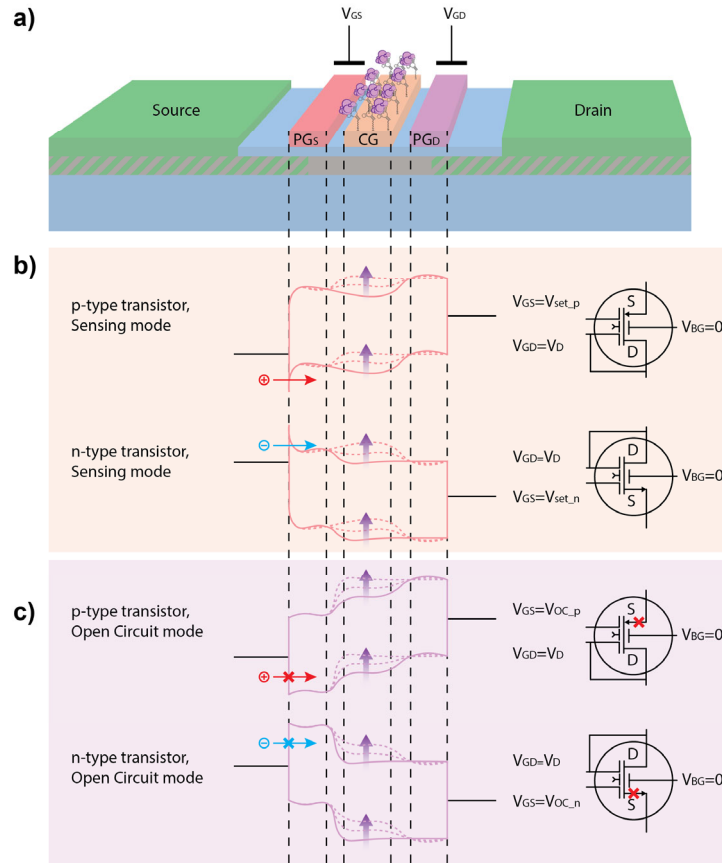
The salty ions are filtered after the dialysis, lowering ionic strength therefore, having a larger Debye length.

In both method the target concentration can be too low to detect.

[2] Chen, H. et al. Dynamic Detection of HbA1c Using a Silicon Nanowire Field Effect Tube Biosensor. Biosensors (Basel) 12, 916 (2022).

Overcoming Debye length screening

Example 2: Reconfigurable field effect transistor



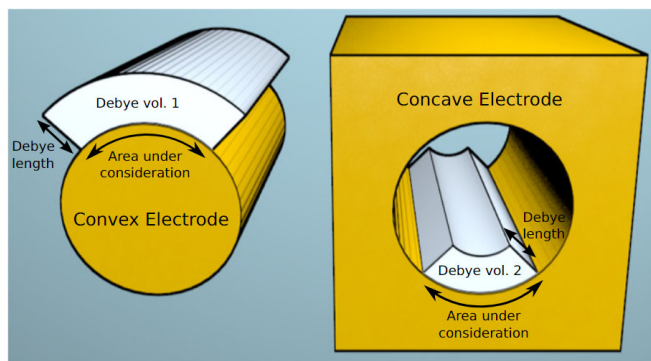
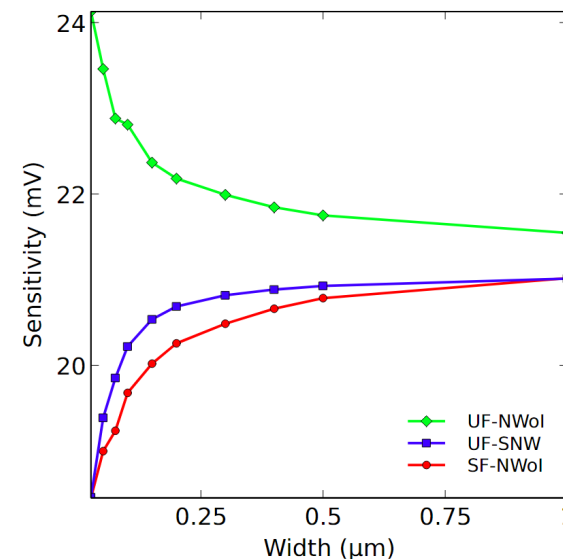
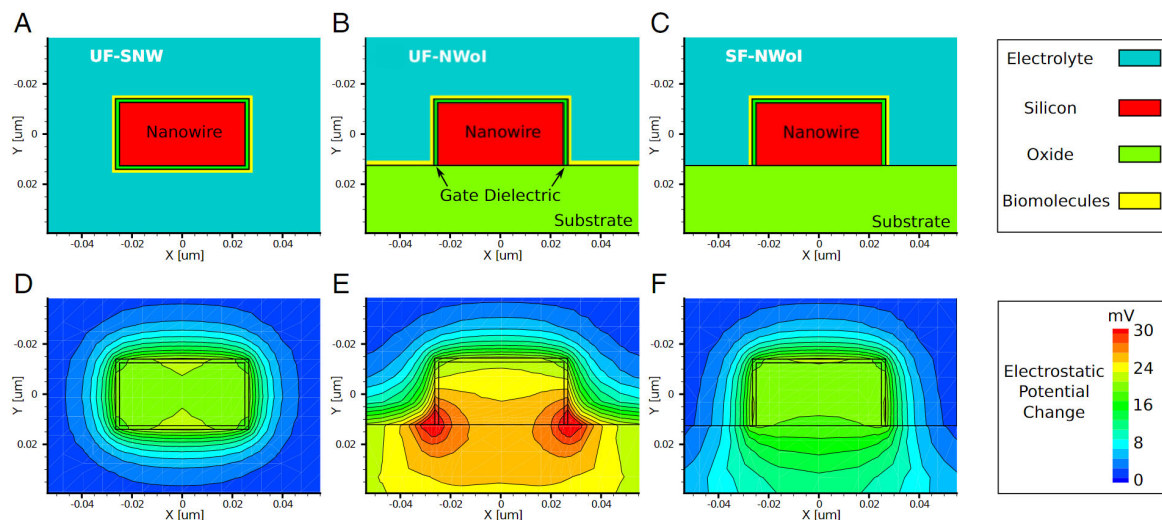
- Metal contact (e.g. Ni, Al)
- Semiconductor (e.g. Si, Ga)
- Dielectric (e.g. SiO₂, HfO₂)

Non doped Si nanowire channel, reducing the EDL at the liquid-solid interface.

Possible semester and master thesis project. Contact me if interested

Overcoming Debye length screening

Example 3: Engineered Si nanowire shape

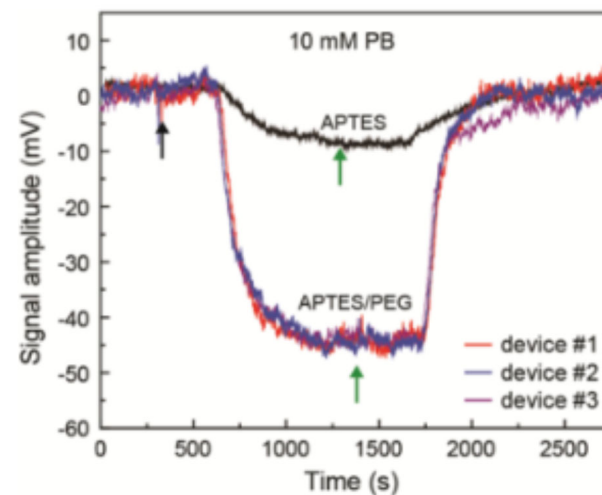
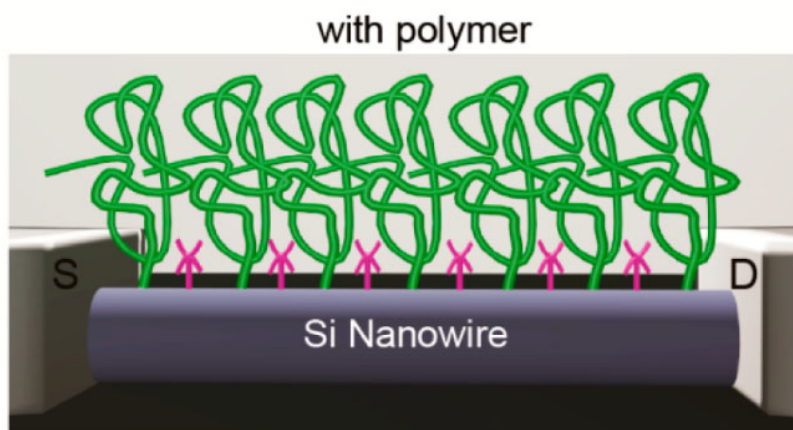
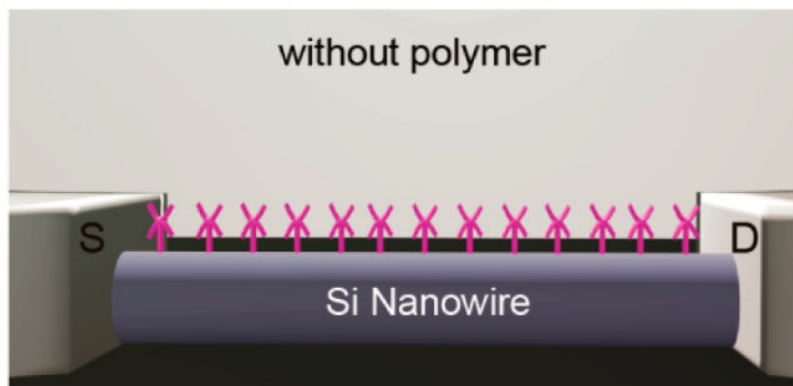


Due to the contribution of changed analyte at the corner, the analytes are brought closer to the nanowire interface, therefore, less Debye length screening.

[3] Shoorideh, K. & Chui, C. O. On the origin of enhanced sensitivity in nanoscale FET-based biosensors. Proceedings of the National Academy of Sciences 111, 5111–5116 (2014).

Overcoming Debye length screening

Example 4: porous and biomolecule permeable polymer



Due to the polarity of the polymer the charge at the nanowire is redistributed resulting in a larger Debye length.

[4] Gao, N. et al. General Strategy for Biodetection in High Ionic Strength Solutions Using Transistor-Based Nanoelectronic Sensors. *Nano Lett.* 15, 2143–2148 (2015).