ISFET structure

Let’s consider the default ISFET structure with default parameters and disabled site-binding charge model (in both DC and AC). We start running two simulations at pH=2 (near the pH of zero charge for SiO₂) and pH=7. Figure 1 illustrates the simulated $I_D$-$V_{FG}$ characteristics. As expected since the site-binding charge model is disabled the curves are essentially insensitive to pH (within numerical error). In fact, the $V_{FG}$ at the target current is essentially the same at the different pH values ($V_T = 0.3534$ V and $V_T = 0.3536$ V, respectively).

Figure 1: $I_D$-$V_{FG}$ characteristic (left) and zoom around the default target current or AC analysis $I_T = 2.5 \times 10^{-8}$ [A/µm] (right) showing that within numerical error the corresponding $V_{FG}$ is essentially insensitive to pH. SiO₂ gate dielectric.

Figure 2: $I_D$-$V_{FG}$ characteristic (left) and zoom around the default target current or AC analysis $I_T = 2.5 \times 10^{-8}$ [A/µm] (right) showing the $V_T$ shift caused by the site-binding charge. SiO₂ gate dielectric.
Figure 2 shows the same simulation with the site-binding charge model active. Now a marked $V_T$ shift from 0.352 V to 0.488 V is observed at the target current. The corresponding $\Delta V_T$ is 136 mV, that is $\approx 27$ mV/pH. This value is, as expected, quite smaller than the so called Nernst limit of sensitivity for ISFETs ($\approx 60$ mV/pH at room temperature), essentially because of the small buffer capacitance of the SiO$_2$ dielectric at small pH values.

Figure 3 replicates a similar experiment with an ISFET featuring the same geometrical and physical parameters except for the gate dielectric material which is now HfO$_2$ and the pH which is set to 7. Note that this pH value essentially coincides with the pHzc for HfO$_2$; consistently, we observe almost no shift of the $I_{DS}$ - $V_{FG}$ characteristic when the site-binding charge model is inactive (left graph). If we now activate he model and simulate at pH=7 and pH=9 the curves shift by approximately 115 mV ($V_T = 0.319$ V and $V_T = 0.434$ V, respectively). The corresponding sensitivity (57.5 mV/pH) is very close to the Nernst limit, as expected for this dielectric.

Figure 3: $I_{DS}$ - $V_{FG}$ characteristic (left) and zoom around the default target current or AC analysis $I_T = 2.5 \times 10^{-8}$ [A/µm] (right) showing the $V_T$ shift caused by the site-binding charge. HfO$_2$ gate dielectric.

Figure 4: $V_T$ at $I_T = 2.5 \times 10^{-8}$ [A/µm] for SiO$_2$ gate dielectric (left) and HfO$_2$ gate dielectric (right) over a broad range of pH values (2-8 for SiO$_2$ and 5-9 for HfO$_2$). We see that between 2 and 4 the sensitivity is very small for SiO$_2$ dielectric whereas an excellent linearity is observed for HfO$_2$ even when crossing the pH of zero charge.

Figure 4 shows the $V_T$ extracted at $I_T = 2.5 \times 10^{-8}$ [A/µm] extracted for SiO$_2$ gate dielectric (left) and HfO$_2$ gate dielectric (right) over a broad range of pH values (2-8 for SiO$_2$ and 5-9 for HfO$_2$). We see that between 2 and 4 the sensitivity is very small for SiO$_2$ dielectric whereas an excellent linearity is observed for HfO$_2$ even when crossing the pH of zero charge.