Predictive Model for HCI (Beta Version)

Hot-carrier-Instability (HCI) manifests itself as an increase in the threshold voltage ($V_{th}$) and the degradation of the carrier mobility, especially for the NMOS transistor.

**Threshold voltage degradation**

The following analytical models describe the shift of $V_{th}$ due to HCI.

\[
\Delta V_{th} = \frac{q}{C_{ox}} K \sqrt{C_{ox} (V_{gs} - V_{th})} \exp\left(\frac{E_{ox}}{E_o}\right) \exp\left(-\frac{\phi_{it}}{q \lambda} E_m^{n}\right) \left(\frac{V_{gs} - V_{th} - 2V_i}{V_{gs} - V_{th} + 2V_i + A_{bulk} L_{eff} E_{sat}}\right)
\]

where,
\[
E_m = \frac{V_{ds} - V_{dat}}{l}, \quad V_{dat} = \frac{(V_{gs} - V_{th} + 2V_i) L_{eff} E_{sat}}{V_{gs} - V_{th} + 2V_i + A_{bulk} L_{eff} E_{sat}}
\]

\[
E_{ox} = \frac{V_{gs} - V_{th}}{T_{ox}}, \quad C_{ox} = \frac{\varepsilon_{ox}}{T_{ox}}, \quad V_i = \frac{kT}{q}
\]

Default values of model coefficients (technology independent):

<table>
<thead>
<tr>
<th>$K$ (nm/C$^{0.5}$)</th>
<th>$E_o$ (V/nm)</th>
<th>$A_{bulk}$</th>
<th>$\phi_{it}$ (eV)</th>
<th>$\lambda$ (nm)</th>
<th>$n$</th>
<th>$L$ (nm)</th>
<th>$E_{sat}$ (V/nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.7e8</td>
<td>0.8</td>
<td>0.005</td>
<td>3.7</td>
<td>7.8</td>
<td>0.45</td>
<td>17</td>
<td>0.011</td>
</tr>
</tbody>
</table>

**Mobility degradation**

\[
\mu = \frac{1}{(1 + \alpha N_i)^m} \mu_{eff}, \quad \text{where} \quad \alpha = 5, m = 1.6,
\]

Nit: interface traps which can be extracted from the threshold voltage degradation model:

\[
\Delta V_{th} = \frac{q}{C_{ox}} N_{it}
\]

**Technology extrapolations:**

<table>
<thead>
<tr>
<th>Technology Node (nm)</th>
<th>250</th>
<th>180</th>
<th>130</th>
<th>90</th>
<th>65</th>
<th>45</th>
<th>32</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{DD}$ (V)</td>
<td>1.8</td>
<td>1.5</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>$V_{th}$ (V)</td>
<td>0.371</td>
<td>0.3</td>
<td>0.265</td>
<td>0.263</td>
<td>0.258</td>
<td>0.257</td>
<td>0.242</td>
</tr>
<tr>
<td>EOT (nm)</td>
<td>4</td>
<td>2.3</td>
<td>1.6</td>
<td>1.4</td>
<td>1.2</td>
<td>1.1</td>
<td>1</td>
</tr>
<tr>
<td>$\mu_{eff}$ (cm$^2$/V/sec)</td>
<td>591</td>
<td>402</td>
<td>295</td>
<td>247</td>
<td>197</td>
<td>166</td>
<td>138</td>
</tr>
</tbody>
</table>