TCAD Simulation of LTPS Hot Carrier Injection Degradation
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Hydrodynamic model for hot carriers:

\[ \nabla \cdot S + R_n w - \nabla E_c \cdot J_n + \frac{n(w - w_0)}{\tau_w} + \frac{\partial (nw)}{\partial t} = 0 \]

\[ S = -\frac{5}{3} J_n w - \frac{10}{9} \mu_n n w \nabla w. \]

where \( w \) is the total energy of an electron and \( w_0 = 3kT/2 \) is the electron energy at equilibrium. \( S \) is the electron energy flux intensity and \( \tau_w \) is the energy relaxation time.

HCI Theory:
Gate injection:
\[
j_{HCI} = q^* \nu_{therm}(T_e) * n_{channel} * prob(T_e)
\]
where \( \nu_{therm} \) is the carrier temperature \( (T_e) \) dependent thermal velocity given by

\[ \nu_{therm} = sqrt\left( \frac{k * T_e}{2 * \pi m * \pi} \right) \]

\( prob(T_e) \) is the probability of carriers with temperature higher than \( T_e \) from TCAD simulation.

To calculate \( prob(T_e) \), we assume Boltzmann statistics due to the lack of quantum confinement for high energy hot carriers:

\[ prob(T_e) = \sum_{\text{over } k_y \text{ for } E > E_{ox}} [ B \exp\left(\frac{-E - E_{c}}{kT_e}\right) ] \]
\[ \text{prob(}T_e\text{)} = \text{sum\_over\_ky\_for\_}E > E_{ox} \left[ B \exp\left(\frac{-(E-E_c)}{kT_e}\right) \right] \]

where \( E \) is carrier energy, \( B \) is normalization constant, \( E_c \) is conduction band edge, and \( E_{ox} \) is oxide barrier energy. The sum over \( ky \) in \( k \)-space can be converted to 1D density of states (DOS) integral and the result can be expressed in \( \text{erfc()} \) function.

One correction to the above is that hot carrier injecting over the oxide barrier into the poly may not be strictly vertical to the channel and the target may have distribution. Here we assume target of HCI follow a normal distribution of the form:

\[
\frac{1}{\sigma\sqrt{2\pi}} \exp\left(-0.5\left(\frac{(x-x_0)}{\sigma}\right)^2\right)
\]

where \( \sigma \) is the standard deviation and \( x_0 \) is the target center.
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Transient Simulation:
1) Using 1sec to ramp up $V_d=10\text{V}$ and $V_g=10\text{V}$.
2) Stay at $V_d=10\text{V}$, $V_g=10\text{V}$ for one month while studying HCI and HCI generated traps at channel/oxide interface.
3) After one month, use 1sec to ramp down $V_d$, $V_g$, and study IV curve to observe any change in threshold voltage.
Before long-term high current stress
After one-month high current stress
Hot carrier injection (HCI) current into the poly gate varies with stress time, indicating change of electrical potential due to the generation of HCI induced interface defects.
Max electron temperature experiences a large initial drop due to the screening of accelerating high field by HCI generated interface traps.
Change of hot-spot carrier concentration indicating variation of electrical potential due to HCI trap generation
0.03V Vth reduction after one-month of high current stress
TAD hot carrier model is suitable for reliability analysis.

Interesting to note that HCI induced traps can screen the high stress field and reduce the hot carrier temperature over time.

With reasonable assumption of HCI induced interface traps, $V_{th}$ degradation can be quantified if proper calibration is done.
Thanks for your attention!