New features in BSIMSOIv3.2

1. The model selector, SoiMod, is an instance parameter and a model parameter. SoiMod will determine the operation of BSIMSOI.

If SoiMod=0 (default), the model equation is identical to BSIMPD equation.

If SoiMod=1 (unified model for PD&FD) or SoiMod=2 (ideal FD), the following equations (FD module) are added on top of BSIMPD.

$$V_{bs0} = \frac{C_{Si}}{C_{Si}+C_{BOX}} \cdot \left(phi - \frac{qN_{ch}\left(1+N_{LX}/L_{eff}\right)}{2\varepsilon_{Si}} \cdot T_{Si}^{2} + V_{nonideal} + \Delta V_{DIBL} \right) + \eta_e \frac{C_{BOX}}{C_{Si}+C_{BOX}} \cdot \left(V_{es} - V_{FBb}\right)$$

$$\text{where } C_{Si} = \frac{\varepsilon_{Si}}{T_{Si}}, C_{BOX} = \frac{\varepsilon_{OX}}{T_{BOX}}, C_{OX} = \frac{\varepsilon_{OX}}{T_{OX}}$$

$$\Delta V_{DIBL} = D_{vbd0} \left(exp\left(-D_{vbd1}\frac{L_{eff}}{2\lambda}\right) + 2exp\left(-D_{vbd1}\frac{L_{eff}}{\lambda}\right) \right) \cdot \left(V_{bi} - 2\Phi_B\right)$$

$$\eta_e = K_{1b} - K_{2b} \cdot \left(exp\left(-D_{k2b}\frac{L_{eff}}{2\lambda}\right) + 2exp\left(-D_{k2b}\frac{L_{eff}}{\lambda}\right) \right)$$

$$phi = phi_{ON} - \frac{C_{OX}}{C_{OX} + \left(C_{Si}^{-1} + C_{BOX}^{-1}\right)^{-1}} \cdot N_{OFF,FD} V_t \cdot ln\left(1 + exp\left(\frac{V_{th,FD} - V_{gs\_eff} - V_{OFF,FD}}{N_{OFF,FD} V_t}\right)\right)$$

$$phi_{ON} = 2\Phi_B + V_t\, ln\left(1 + \frac{V_{gsteff,FD}\left(V_{gsteff,FD} + 2K1\sqrt{2\Phi_B}\right)}{MoinFD \cdot K1 \cdot V_t^{2}}\right),$$

$$V_{gsteff,FD} = N_{OFF,FD} V_t \cdot ln\left(1 + exp\left(\frac{V_{gs\_eff} - V_{th,FD} - V_{OFF,FD}}{N_{OFF,FD} V_t}\right)\right)$$

Here N_{ch} is the channel doping concentration. N_{LX} is the lateral non-uniform doping coefficient to account for the lateral non-uniform doping effect. V_{FBb} is the backgate flatband voltage. $V_{th,FD}$ is the threshold voltage at $V_{bs}=V_{bs0}$(phi=$2\Phi_B$). V_t is thermal voltage. K1 is the body effect coefficient.

If SoiMod=1, the lower bound of V_{bs} (SPICE solution) is set to V_{bs0}. If SoiMod=2, V_{bs} is pinned at V_{bs0}. Notice that there is no body node and body leakage/charge calculation in SoiMod=2.

The zero field body potential that will determine the transistor threshold voltage, V_{bsmos}, is then calculated by

$$
\begin{aligned}
V_{bsmos} &= V_{bs} - \frac{C_{Si}}{2qN_{ch}T_{Si}}\left(V_{bs0}\left(T_{OX} \to \infty\right) - V_{bs}\right)^2 \quad \text{if } V_{bs} \le V_{bs0}\left(T_{OX} \to \infty\right) \\
&= V_{bs} \quad \text{else}
\end{aligned}
$$

The subsequent clamping of V_{bsmos} will use the same equation that utilized in BSIMPD. Please download the BSIMPD manual at (www-device.eecs.Berkeley.edu/~bsimsoi).

2. If SoiMod=3 is specified, BSIMSOI will select the operation mode for the user based on the estimated value of V_{bs0} at phi=$2\Phi_B$ (bias independent), V_{bs0t}:

If $V_{bs0t} > V_{bs0fd}$, BSIMSOI will be in the ideal FD mode (SoiMod=2).
If $V_{bs0t} < V_{bs0pd}$, BSIMSOI will be in the BSIMPD mode (SoiMod=0).
Otherwise, BSIMSOI will be operated under SoiMod=1.

Notice that both V_{bs0fd} and V_{bs0pd} are model parameters.

3. A new model parameter, T_{OXM}, is introduced to represent the T_{OX} dependence for the model parameters K1 and K2 (compatible to BSIM3v3.2).

4. A new model parameter, N_{OFF}, is introduced in $V_{gsteff,cv}$ to adjust the CV curve around threshold (compatible to BSIM3v3.2).

5. BSIMSOI3.2 noise model

In BSIMSOI3.2 beta version, flicker noise and thermal noise model compatible with BSIM4 has been implemented. In addition, gate tunneling induced shot noise and thermal noise due to gate electrode resistance are included.

(1) Flicker noise models

BSIMSOI3.2 provides two flicker noise models. When the model selector fnoiMod is set to 0, a simple flicker noise model which is convenient for hand calculation is invoked. A unified physical flicker noise model, which is the default model, will be used if fnoiMod=1. These two modes come from BSIMSOI3.1, but the unified model has many improvements. For instance, it is now smooth over all bias regions and considers the bulk charge effect.

- fnoiMod = 0 (simple model)

The noise density is:

$$S_{id}(f) = \frac{K_f I_{ds}^{af}}{C_{ox} L_{eff}^2 f^{ef}}$$

- fnoiMOd = 1 (unified model)

The physical mechanism for the flicker noise is trapping/de-trapping related charge fluctuation in oxide traps, which results in fluctuations of both mobile carrier numbers and mobility in the channel. The unified flicker noise model captures this physical process.

The noise density in inversion region is given by:

$$S_{id,inv}(f) = \frac{k_B T q^2 m_{eff} I_{ds}}{C_{oxe} L_{eff}^2 A_{bulk} f^{ef} \cdot 10^{10}} \left(NOIA \log\left(\frac{N_0 + N^*}{N_l + N^*}\right) + NOIB(N_0 - N_l) + \frac{NOIC}{2}(N_0^2 - N_l^2) \right)$$
$$+ \frac{k_B T I_{ds}^2 \Delta L_{clm}}{W_{eff} L_{eff}^2 f^{ef} \cdot 10^{10}} \frac{NOIA + NOIB \cdot N_l + NOIC \cdot N_l^2}{(N_l + N^*)^2}$$

where m_{eff} is the effective mobility at the given bias condition, and L_{eff} and W_{eff} are the effective length and width respectively. The parameter N_0 is the charge density at the source side given by:

$$N_0 = \frac{C_{ox} V_{gsteff}}{q}$$

The parameter N_l is the charge density at the source side given by:

$$N_l = \frac{C_{ox} V_{gsteff}}{q} \left(1 - \frac{A_{bulk} V_{dseff}}{V_{gsteff} + 2v_t} \right)$$

N^* is given by:

$$N^* = k_B T \cdot (C_{ox} + C_d + CIT) \Big/ q^2$$

where CIT is a model parameter from DC IV and C_d is the depletion capacitance.

ΔL_{clm} is the channel length reduction due to channel length modulation and given by:

$$\Delta L_{clm} = Litl \cdot \log\left(\frac{\frac{V_{ds} - V_{dseff}}{Litl} + EM}{E_{sat}} \right)$$

$$E_{sat} = \frac{2VSAT}{m_{eff}}$$

In the subthreshold region, the noise density is written as:

$$S_{id,subVt}(f) = \frac{NOIA \cdot k_B T \cdot I_{ds}^2}{W_{eff} L_{eff} f^{EF} N^{*2} \cdot 10^{10}}$$

The total flicker noise density is

$$S_{id}(f)=\frac{S_{id,inv}(f)\times S_{id,subvt}(f)}{S_{id,inv}(f)+S_{id,subvt}(f)}$$

(2) Thermal noise models

There are two channel thermal noise models in BSIMSOI3.2 beta version. One is the charge based model (default) similar to that used in BSIMSOI3.1. The other is the holistic model. These two models can be selected through the model selector tnoiMod.

- tnoiMod = 0 (charge based)

The nosie current is given by

$$\overline{i_d^2}=\frac{4k_B T\Delta f}{R_{ds}+\dfrac{L_{eff}^2}{m_{eff}\left|Q_{inv}\right|}}\cdot NTNOI\ ,$$

where R_{ds} is the source/drain resistance, and the parameter $NTNOI$ is introduced fro more accurate fitting of short-channel devices. Q_{inv} is the inversion channel charge computed from the capacitance models

- tnoiMod = 1 (holistic)

In this thermal noise model, all the short-channel effects and velocity saturation effect incorporated in the IV model are automatically included, hence the name “holistic thermal noise model”. In addition, the amplification of the channel thermal noise through G_m and G_{mbs} as well as the induced-gate noise with partial correlation to the channel thermal noise are all captured in the new “noise partition” model.

The noise voltage source partitioned to the source side is given by:

$$\overline{v_d^2}=4k_B T\cdot q_{tnoi}^2\cdot\frac{V_{dseff}\Delta f}{I_{ds}}$$

and the noise current source put in the channel region with gate and body amplification is given by:

$$\overline{i_d^2}=4k_B T\frac{V_{dseff}\Delta f}{I_{ds}}\left[G_{ds}+b_{tnoi}\cdot\left(G_m+G_{mbs}\right)\right]^2-\overline{v_d^2}\cdot\left(G_m+G_{ds}+G_{mbs}\right)^2$$

where

$$q_{tnoi}=RNOIB\cdot\left[1+TNOIB\cdot L_{eff}\left(\frac{V_{gsteff}}{E_{sat}L_{eff}}\right)^2\right]$$

$$b_{tnoi}=RNOIA\cdot\left[1+TNOIA\cdot L_{eff}\left(\frac{V_{gsteff}}{E_{sat}L_{eff}}\right)^2\right]$$

New model parameters in BSIMSOIv3.2

Symbol used in equation	Symbol used in SPICE	Description	Unit	Default
SoiMod	soiMod	SOI model selector (instance). SoiMod=0: BSIMPD. SoiMod=1: unified model for PD&FD. SoiMod=2: ideal FD. SoiMod=3: auto selection by BSIMSOI	-	0
T_{OXM}	toxm	Gate oxide thickness used in extraction	m	T_{OX}
N_{OFF}	noff	CV parameter for $V_{gsteff,cv}$	-	1.0
V_{bs0pd}	vbs0pd	Upper bound of built-in potential lowering for BSIMPD operation	V	0.0
V_{bs0fd}	vbs0fd	Lowering bound of built-in potential lowering for ideal FD operation	V	0.5
fnoiMod	fnoiMod	Flicker noise model selector	-	1
tnoiMod	fnoiMod	Thermal noise model selector	-	0
NTNOI	ntnoi	Noise factor for short-channel devices for TNOIMOD=0 only	-	1.0
TNOIA	tnoia	Coefficient of channel-length dependence of total channel thermal noise	-	1.5
TNOIB	tnoib	Channel-length dependence parameter for channel thermal noise partitioning	-	3.5
RNOIA	rnoia	Thermal noise parameter	-	0.577
RNOIB	rnoib	Thermal noise parameter	-	0.37