BSIM 4.6.1 - Release
Enhancements over BSIM4.6.0

Mohan V. Dunga, Morgan Young,
Ali M. Niknejad, Chenming Hu

Dept. of Electrical Engineering and Computer Sciences,
University of California, Berkeley

May 2007

Model Enhancements

- Error in the derivative calculation for dVdseffCV_dVb is fixed within b4ld.c.
- Warning messages about the limits on NOFF and VOFFCV are removed in b4check.c.
- The C-V model is enhanced by adding a new definition for *VgsteffCV* to improve the sub-threshold fitting.
- New Material Model is introduced for predictive modeling of non-SiO_2 insulator, non-poly Si gate and non-Si channel.
- Mobility model, GIDL/GISL and Poly depletion models are made more predictive.

Bug Fix : dVdseffCV_dVb

- Reported by Geoffery Coram (ADI)
- Error in the derivative calculation for dVdseffCV_dVb fixed within b4ld.c.
- The following lines in the code have been modified :

Capmod = 1

OLD : dVdseffCV_dVb = dT0_dVb * (1.0 - T5) + T5 * dT1_dVb;

NEW : dVdseffCV_dVb = dT0_dVb * (T4 - T5) + T5 * dT1_dVb;

Capmod=2

OLD : dVdseffCV_dVb = dT0_dVb * (1.0 - T5) + T5 * dT1_dVb;

NEW : dVdseffCV_dVb = dT0_dVb * (T4 - T5) + T5 * dT1_dVb;

Changes to b4check.c

- Warning messages about the limits on NOFF and VOFFCV have been removed.

C-V Model

- A new *VgsteffCV* definition is introduced into C-V model to improve sub-threshold fitting.
- Setting CVCHARGEMOD = 1 activates the new VgsteffCV calculation which is similar to the Vgsteff formulation in the I-V model.

$$V_{gsteffCV} = \frac{nv_t \ln\left(1+\exp\left(\frac{m^*\left(V_{gse}-V_{th}\right)}{nv_t}\right)\right)}{m^* + nC_{oxe}\sqrt{\frac{2f_s}{qNDEPe_{Si}}}\exp\left(-\frac{\left(1-m^*\right)\left(V_{gse}-V_{th}\right)-Voff'}{nv_t}\right)}$$

$$m^* = 0.5 + \frac{\arctan\left(MINVCV\right)}{p} \qquad Voff' = VOFFCV + \frac{VOFFCVL}{L_{eff}}$$

- Setting CVCHARGEMOD = 0 defaults C-V model to BSIM4.6.0.
- 6 new parameters added :
  - CVCHARGEMOD, MINVCV, LMINVCV, WMINVCV, PMINVCV and VOFFCVL

New Material Model

- A new materials model is introduced with the following features:
  - Predictive modeling of
    - Non-SiO2 insulator
    - Non-poly-Si gate
    - Non-silicon channel
  - Improved predictive models for GIDL/GISL leakage current, mobility degradation and short channel effects
  - A model selector (MTRLMOD) is used to turn on/off all the new materials parameters/equations, thus maintains backward compatibility

New Materials Model : New Parameters

- Model selector:
  - MTRLMOD : =1 activates the new-materials option and =0 (default) deactivates

- For non-poly-silicon gate:
  - PHIG : Gate work function
  - EPSRGATE : Dielectric constant of gate relative to vacuum (= 0 deactivates poly depletion)

- For non-SiO2 gate-dielectric:
  - EOT : Equivalent SiO2 thickness
  - VDDEOT : Gate voltage at which EOT is measured

- For non-silicon channel material:
  - EASUB : Electron affinity of substrate
  - EPSRSUB : Dielectric constant of substrate relative to vacuum
  - NI0SUB : Intrinsic carrier concentration at T=300.15K
  - BG0SUB : Band-gap of substrate at T=0K
  - TBGASUB : First parameter of band-gap change due to temperature
  - TBGBSUB : Second parameter of band-gap change due to temperature
  - ADOS : Density of states parameter to control charge centroid
  - BDOS : Density of states parameter to control charge centroid

Non-Silicon Channel Material

- Define the temperature-dependent intrinsic carrier concentrations and the band gap with the new non-silicon parameters for MTRLMOD = 1.

$$Eg0 = BG0SUB - \frac{TBGASUB * Tnom^2}{Tnom + TBGBSUB}$$

$$Eg(300.15) = BG0SUB - \frac{TBGASUB * 300.15^2}{300.15 + TBGBSUB}$$

$$ni = NI0SUB * \left(\frac{Tnom}{300.15}\right)^{3/2} \cdot e^{\frac{Eg(300.15K) - Eg0}{2V_t}}$$

$$Eg = BG0SUB - \frac{TBGASUB * Temp^2}{Temp + TBGBSUB}$$

Non-Silicon Channel Material

- For MTRLMOD = 1, replace the hard coded dielectric constant of 11.7 (for silicon) with EPSRSUB.

- Change hard coded ratio of channel and insulator dielectric-constants (3.0 for Si/SiO2), e.g.

$$litl = \sqrt{3.0 \cdot TOXE \cdot XJ} \longrightarrow litl = \sqrt{\frac{EPSRSUB \cdot EOT \cdot XJ}{3.9 * 8.854 * 10^{-12}}}$$

- Introduce two new parameters for charge centroid for non-silicon channel materials in both I-V and C-V models.

$$X_{dc} = \frac{ADOS \times 1.9 \times 10^{-9}}{1 + \left(\frac{Vgsteff + (VTH0 - VFB - \phi_s)}{2toxp}\right)^{0.7 \times BDOS}}$$

Non-SiO$_2$ Dielectric Material

- Change hard coded ratio of channel and insulator dielectric-constants (3.0 for Si/SiO2), e.g.

$$litl = \sqrt{3.0 \cdot TOXE \cdot XJ} \longrightarrow litl = \sqrt{\frac{EPSRSUB \cdot EOT \cdot XJ}{3.9 * 8.854 * 10^{-12}}}$$

- For MTRLMOD = 1, use EOT (defined as the electrical oxide thickness at V_{gs} = VDDEOT) to calculate oxide thickness at flatband voltage.

$$Toxp = EOT - \frac{3.9}{EPSRSUB} \cdot X_{dc}|_{Vgs=VDDEOT, V_{ds}=V_{bs}=0}$$

Non-poly-Si gate Material

- Poly depletion is calculated using the following equation :

$$V_{gse} = VFB + \Phi_s + \frac{q\varepsilon_{gate} NGATE}{coxe^2}\left(\sqrt{1 + \frac{2coxe^2\left(V_{gs} - VFB - \Phi_s\right)}{q\varepsilon_{gate} NGATE}} - 1\right)$$

where

$$\begin{aligned} \varepsilon_{gate} &= EPSRGATE \cdot EPS0 \quad \text{for MTRLMOD = 1} \\ &= EPSSI \quad \text{for MTRLMOD = 0} \end{aligned}$$

- Setting EPSRGATE = 0 turns the poly depletion model off.

Improved Mobility Model

- For MTRLMOD = 1, mobility degradation uses a new definition of vertical field.

$$E_{eff} = \frac{V_{gsteff} + 2V_{th} - 2 * BSIM4type * (PHIG - EASUB - Eg/2 + 0.45)}{EOT} \cdot \frac{3.9}{EPSRSUB}$$

- MOBMOD = 0 and MOBMOD = 1 are changed accordingly.

MOBMOD = 0

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + \left(UA + UC \cdot V_{bseff}\right) E_{eff} + UB \cdot E_{eff}^2 + UD \left(\frac{V_{th} \cdot EOT}{V_{gsteff} + 2\sqrt{V_{th}^2 + 0.00001}}\right)^2}$$

MOBMOD = 1

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + \left(UA \cdot E_{eff} + UB \cdot E_{eff}^2\right)\left(1 + UC \cdot V_{bseff}\right) UD \left(\frac{V_{th} \cdot EOT}{V_{gsteff} + 2\sqrt{V_{th}^2 + 0.00001}}\right)^2}$$

Improved GIDL/GISL Model

- For MTRLMOD = 1, the flat band voltage at Source/Drain is calculated using

$$V_{fbsd} = PHIG - \left(EASUB + \frac{Eg0}{2} - BSIM4type \cdot MIN\left(\frac{Eg0}{2}, V_t \ln\left(\frac{NSD}{ni}\right)\right)\right)$$

- For MTRLMOD = 1, GIDL/GISL is given by

$$I_{GIDL} = AGIDL \cdot W_{effCJ} \cdot Nf \cdot \frac{V_{ds} - V_{gse} - EGIDL + V_{fbsd}}{EOT \cdot \frac{EPSRSUB}{3.9}} \cdot exp\left(-\frac{EOT \cdot \frac{EPSRSUB}{3.9} \cdot BGIDL}{V_{ds} - V_{gse} - EGIDL + V_{fbsd}}\right) \cdot \frac{V_{db}^3}{CGIDL + V_{db}^3}$$

$$I_{GISL} = AGISL \cdot W_{effCJ} \cdot Nf \cdot \frac{-V_{ds} - V_{gse} - EGISL + V_{fbsd}}{EOT \cdot \frac{EPSRSUB}{3.9}} \cdot exp\left(-\frac{EOT \cdot \frac{EPSRSUB}{3.9} \cdot BGISL}{-V_{ds} - V_{gse} - EGISL + V_{fbsd}}\right) \cdot \frac{V_{sb}^3}{CGISL + V_{sb}^3}$$