BSIM 4.6.0 - Release
Enhancements over BSIM4.5.0

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GISL / GIDL Leakage Module

- In BSIM 4.5.0, both I_{GISL} and I_{GIDL} share the same set of parameters – AGIDL, BGIDL, CGIDL and EGIDL.

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

$$I_{GISL} = AGIDL \cdot W_{effCJ} \cdot Nf \cdot \frac{-V_{ds} - V_{gde} - EGIDL}{3 \cdot T_{oxe}} \cdot \exp\left(- \frac{3 \cdot T_{oxe} \cdot BGIDL}{-V_{ds} - V_{gde} - EGIDL} \right) \cdot \frac{V_{sb}^3}{CGIDL + V_{sb}^3}$$

- In BSIM 4.6.0, the parameters for I_{GISL} and I_{GIDL} are different.
- 4 new parameters – AGISL, BGISL, CGISL and EGISL have been added.

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

$$I_{GISL} = AGISL \cdot W_{effCJ} \cdot Nf \cdot \frac{-V_{ds} - V_{gde} - EGISL}{3 \cdot T_{oxe}} \cdot \exp\left(- \frac{3 \cdot T_{oxe} \cdot BGISL}{-V_{ds} - V_{gde} - EGISL} \right) \cdot \frac{V_{sb}^3}{CGISL + V_{sb}^3}$$

GISL / GIDL Leakage Module

- To maintain backward compatibility with BSIM4.5.0, if AGISL is not given, it defaults to AGIDL.
- The other three new parameters default in the same way.
- All the four new parameters AGIDL, BGIDL, CGIDL and EGIDL parameters are binnable and the corresponding L, W and P binning parameters have been added.

Junction Diode I-V

- In BSIM4.5.0, the junction diode current due to the trap-assisted tunneling current in space-charge region has same set of parameters for both source and drain junctions.
- In BSIM4.6.0, the parameters for source and drain side are separate.
- 6 new parameters are added for the drain side.
- The parameters for the source and drain side are :
  - Source : NJTS, NJTSSW, NJTSSWG, TNJTS, TNJTSSW, TNJTSSWG.
  - Drain : NJTSD, NJTSSWD, NJTSSWGD, TNJTSD, TNJTSSWD, TNJTSSWGD.
- To maintain backward compatibility with BSIM4.5.0, if NJTSD is not given, it defaults to NJTS.
- The other five new parameters default in the same way.

Junction Diode I-V

- The diode I-V model including trap-assisted tunneling for BSIM4.6.0 is :

$$I_{bs\_total} = I_{bs}$$

$$-W_{effcj}\cdot NF\cdot J_{tsswgs}(T)\cdot\left[\exp\left(\frac{-V_{bs}}{NJTSSWG(T)\cdot Vtm0}\cdot\frac{VTSSWGS}{VTSSWGS-V_{bs}}\right)-1\right]$$

$$-P_{s,deff}\,J_{tssws}(T)\left[\exp\left(\frac{-V_{bs}}{NJTSSW(T)\cdot Vtm0}\cdot\frac{VTSSWS}{VTSSWS-V_{bs}}\right)-1\right]$$

$$-A_{s,deff}\,J_{tss}(T)\left[\exp\left(\frac{-V_{bs}}{NJTS(T)\cdot Vtm0}\cdot\frac{VTSS}{VTSS-V_{bs}}\right)-1\right]+g_{`\min}\cdot V_{bs}$$

$$NJTS(T)=NJTS(TNOM)\cdot\left[1+TNTJS\left(\frac{T}{TNOM}-1\right)\right]$$

$$NJTSSW(T)=NJTSSW(TNOM)\cdot\left[1+TNJTSSW\left(\frac{T}{TNOM}-1\right)\right]$$

$$NJTSSWG(T)=NJTSSWG(TNOM)\cdot\left[1+TNJTSSWG\left(\frac{T}{TNOM}-1\right)\right]$$

$$I_{bd\_total} = I_{bd}$$

$$-W_{effcj}\cdot NF\cdot J_{tsswgd}(T)\cdot\left[\exp\left(\frac{-V_{bd}}{NJTSSWGD(T)\cdot Vtm0}\cdot\frac{VTSSWGD}{VTSSWGD-V_{bd}}\right)-1\right]$$

$$-P_{d,deff}\,J_{tsswd}(T)\left[\exp\left(\frac{-V_{bd}}{NJTSSWD(T)\cdot Vtm0}\cdot\frac{VTSSWD}{VTSSWD-V_{bd}}\right)-1\right]$$

$$-A_{d,deff}\,J_{tsd}(T)\left[\exp\left(\frac{-V_{bd}}{NJTSD(T)\cdot Vtm0}\cdot\frac{VTSD}{VTSD-V_{bd}}\right)-1\right]+g_{`\min}\cdot V_{bd}$$

$$NJTSD(T)=NJTSD(TNOM)\cdot\left[1+TNTJSD\left(\frac{T}{TNOM}-1\right)\right]$$

$$NJTSSWD(T)=NJTSSWD(TNOM)\cdot\left[1+TNJTSSWD\left(\frac{T}{TNOM}-1\right)\right]$$

$$NJTSSWGD(T)=NJTSSWGD(TNOM)\cdot\left[1+TNJTSSWGD\left(\frac{T}{TNOM}-1\right)\right]$$

Gate Tunneling Current I_{GS} / I_{GD}

- In BSIM4.5.0, the gate tunneling current in the overlapping S/D diffusion regions (I_{GS} / I_{GD}) share the same set of parameters for both source and drain (DLCIG, AIGSD, BIGSD, CIGSD).
- In BSIM4.6.0, the parameters for I_{GS} and I_{GD} are separate.
- The parameters for I_{GS} and I_{GD} are :
  - I_{GS} : DLCIG, AIGS, BIGS, CIGS
  - I_{GD} : DLCIGD, AIGD, BIGD, CIGD
- The parameters from BSIM4.5.0 are retained for backward compatibility.
- To maintain backward compatibility with BSIM4.5.0, if AIGSD is specified, then set AIGS = AIGD = AIGSD.
- The other parameters follow the same rule for backward compatibility.

Gate Tunneling Current I_{GS} / I_{GD}

- In BSIM4.6.0, the gate tunneling currents I_{GS} and I_{GD} are given by :

$$Igs = W_{eff}\, DLCIG \cdot A \cdot T_{oxRatioEdge} \cdot V_{gs} \cdot V_{gs}'$$
$$\cdot \exp\left[-B \cdot TOXE \cdot POXEDGE \cdot \left(AIGS - BIGS \cdot V_{gs}'\right) \cdot \left(1 + CIGS \cdot V_{gs}'\right)\right]$$

$$Igd = W_{eff}\, DLCIGD \cdot A \cdot T_{oxRatioEdge} \cdot V_{gd} \cdot V_{gd}'$$
$$\cdot \exp\left[-B \cdot TOXE \cdot POXEDGE \cdot \left(AIGD - BIGD \cdot V_{gd}'\right) \cdot \left(1 + CIGD \cdot V_{gd}'\right)\right]$$

- The new parameters AIGS, BIGS, CIGS, AIGD, BIGD and CIGD are binnable and the corresponding new L, W and P binning parameters have also been added.

Coulomb Scattering Mobility Model

- A new term was added in the mobility model to capture the Coulomb scattering effect in the BSIM4.5.0 release.

mobMod = 0

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

mobMod = 1

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

mobMod = 2

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + (UA + UC \cdot V_{bseff}) \left[\frac{V_{gsteff} + C_0 (VTHO - VFB - \Phi_s)}{TOXE} \right]^{EU} + UD \left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2V_{th}} \right)^2}$$

Coulomb Scattering Mobility Model

- The coulomb scattering term has been modified in BSIM4.6.0 release to avoid the possibility of non-monotonic drain current trend with respect to gate voltage.

mobMod = 0

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + \left(UA + UCV_{bseff}\right)\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right) + UB\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right)^2 + UD\left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2\sqrt{V_{th}^{\ 2} + 0.0001}}\right)^2}$$

mobMod = 1

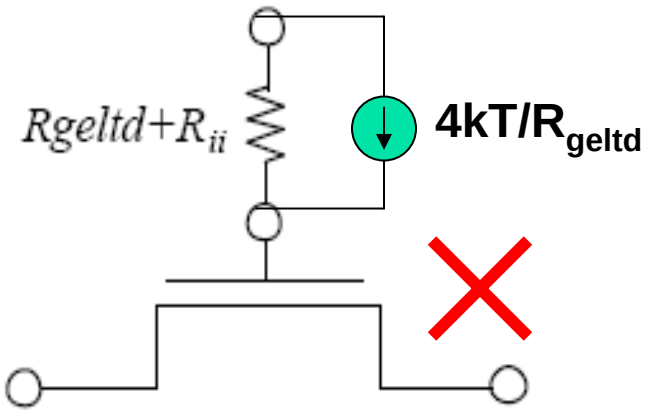
$$\mu_{eff} = \frac{U0 \cdot f\left(L_{eff}\right)}{1 + \left(UA + UC \cdot V_{bseff}\right)\left[\frac{V_{gsteff} + C_0 \cdot \left(VTHO - VFB - \Phi_s\right)}{TOXE}\right]^{EU} + UD\left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2\sqrt{V_{th}^{\ 2} + 0.0001}}\right)}$$

mobMod = 2

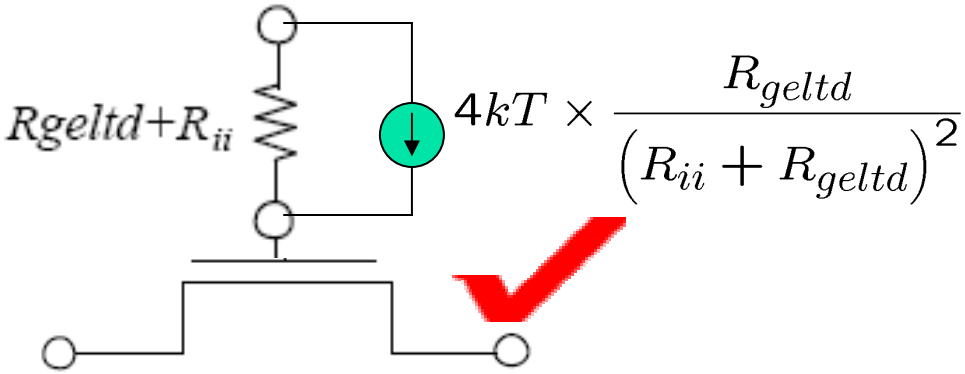
$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + \left[UA\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right) + UB\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right)^2\right]\left(1 + UC \cdot V_{bseff}\right) + UD\left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2\sqrt{V_{th}^{\ 2} + 0.0001}}\right)^2}$$

Improvement to NOIMOD = 2

- Bug reported by Mentor Graphics.
- Erroneous drain current noise obtained in certain simulations while using NOIMOD = 2
- When NOIMOD = 2, the effective noise resistance used in b4noi.c is wrong as shown below.



BSIM4.5.0 Model Implementation



CORRECT Model Implementation

Improvement to NOIMOD = 2

- In b4noi.c, replace the noise resistance R_{geltd} by the following resistor

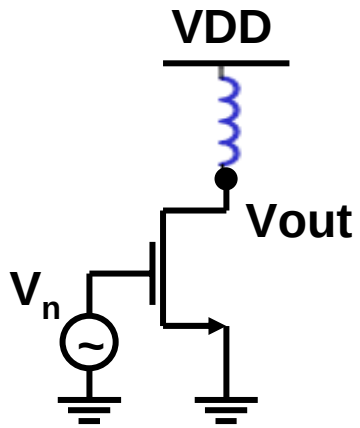
$$R_{geltd} \times \left(1 + \frac{R_{ii}}{R_{geltd}}\right)^2$$

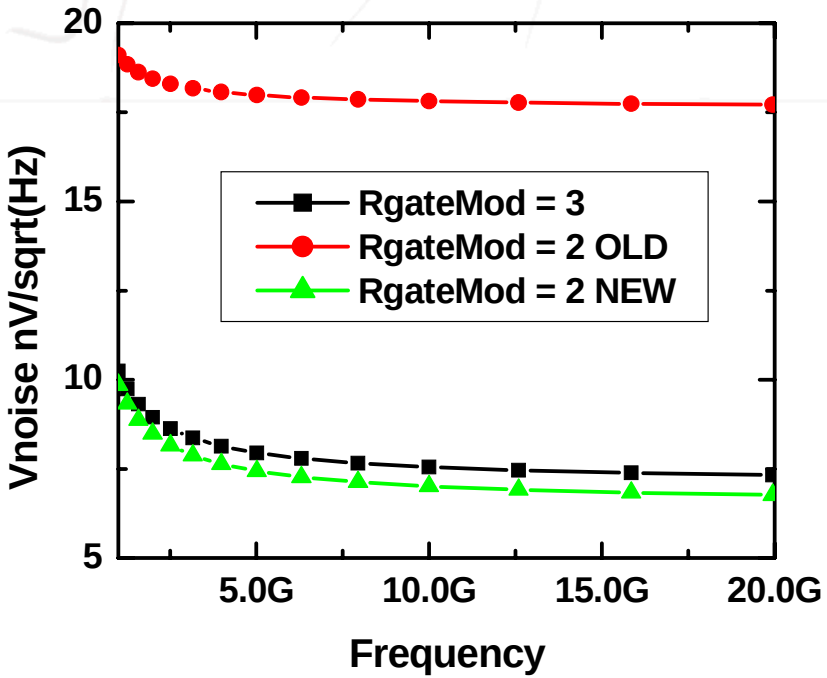
- Note that the change in NOIMOD=2 in BSIM4.6.0 is backward compatible with BSIM4.5.0.
- Change the code in b4noi.c. (red is deletion, blue is addition)

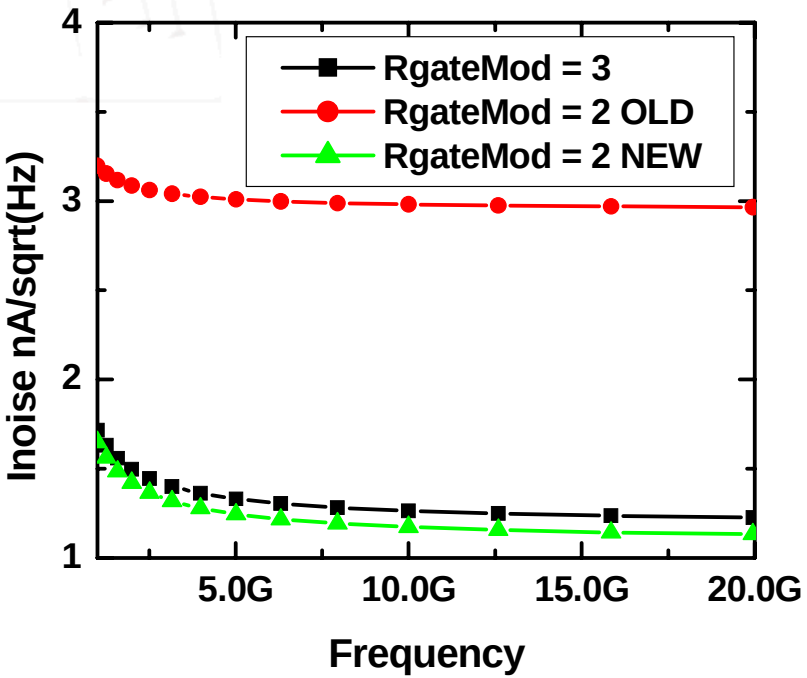
```
if ((here->BSIM4rgateMod == 1) || (here->BSIM4rgateMod == 2))
                    {   NevalSrc(&noizDens[BSIM4RGNOIZ],
                            &lnNdens[BSIM4RGNOIZ], ckt, THERMNOISE,
                            here->BSIM4gNodePrime, here->BSIM4gNodeExt,
                            here->BSIM4grgeltd);
                    }
else if (here->BSIM4rgateMod == 2)
                    {
                     T0 = 1.0 + here->BSIM4grgeltd/here->BSIM4gcrg;
                     T1 = T0 * T0;
                      NevalSrc(&noizDens[BSIM4RGNOIZ],
                            &lnNdens[BSIM4RGNOIZ], ckt, THERMNOISE,
                            here->BSIM4gNodePrime, here->BSIM4gNodeExt,
                            here->BSIM4grgeltd/T1);
                    }
```

Improvement to NOIMOD = 2

- Model verified for a case where R_{ii} = 4 * R_{geltd}
- New noise resistor predicts noise closer to RgateMod = 3 unlike the old one.







Bug Fix : b4set.c

- The model parameter VFB was not initialized in BSIM4.5.0.
- b4set.c has been modified to initialize VFB parameter.
- The following lines have been added to the code in b4set.c :

```
if (!model->BSIM4vfbGiven)
    model->BSIM4vfb = -1.0;
```

Changes to Manual

- The relevant chapters in the manual have been updated (Ch-4, 5, 6, 10, 12).
- Impact Ionization parameter list in Appendix-A has been updated to reflect the correct model parameters. The model equation in Ch-6 has also been corrected.
- The guidelines for extracting the Well proximity model parameters (Ch-14) have been removed and reference to the CMC WPE parameter extraction document has been provided.