Summary of Changes from BSIM-BULK 107.2.0 to BSIM-BULK 107.2.1:

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BSIM-BULK 107.2.1_beta1

A.Summary of bug-fixes:

1. **2024bug18 (Cadence)**: Derivative discontinuity in BSIM-BULK source/drain junction current.
2. **2024bug19 (Infineon):** devsign erroneously used in expansion effect model.
3. **2024bug20 (Infineon):** Expansion effect model impacts the non-expansion effect region.
4. **2024bug21 (Cadence):** Discontinuity issue in the gmbs derivative

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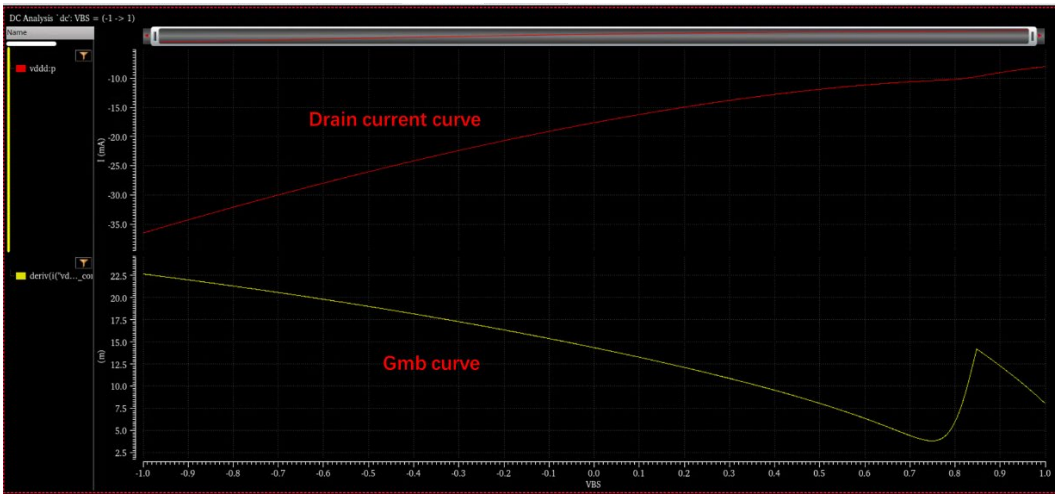
A. Description of bug-fixes:

1. 2024bug18 (Cadence): Derivative discontinuity in BSIM-BULK source/drain junction current.

- In BSIM-BULK 107.2.0, $\frac{\partial I_D}{\partial V_b}$ is continuous for default value of RSH.
- However, for higher values of RSH (say 18.5), $\frac{\partial I_D}{\partial V_b}$ is discontinuous.



- If-else condition based Ibs expression switching (which models forward and reverse diode breakdown limiting current) is the reason for the discontinuity seen in the derivatives in BSIM-BULK 107.2.0

BSIM-BULK 107.2.0

```
3985    ····//·Junction·currents·and·capacitances
3986    ····//·Source-side·junction·currents
3987    ····if·(Isbs·>·0.0)·begin
3988    ····    if·(Vbs_jct·<·VjsmRev)·begin
3989    ····        T0··=·Vbs_jct·/·Nvtms;
3990    ····        T1··=·lexp(T0)·-·1.0;
3991    ····        T2··=·IVjsmRev·+·SslpRev·*·(Vbs_jct·-·VjsmRev);
3992    ····        Ibs·=·T1·*·T2;
3993    ····    end·else·if·(Vbs_jct·<=·VjsmFwd)·begin
3994    ····        T0··=·Vbs_jct·/·Nvtms;
3995    ····        T1··=·(BVS·+·Vbs_jct)·/·Nvtms;
3996    ····        T2··=·lexp(-T1);
3997    ····        Ibs·=·Isbs·*·(lexp(T0)·+·XExpBVS·-·1.0·-·XJBVS·*·T2);
3998    ····    end·else·begin
3999    ····        Ibs·=·IVjsmFwd·+·SslpFwd·*·(Vbs_jct·-·VjsmFwd);
4000    ····    end
4001    ····end·else·begin
4002    ····    Ibs·=·0.0;
4003    ····end

4816    ····IBS···=·-devsign·*·Ibs;··//·Source·junction·current
```

- In BSIM-BULK 107.2.1beta1, tanh function is used as follows to smoothly stitch the if-else condition expressions:

BSIM-BULK 107.2.1beta1

```
4215    ····//·Junction·currents·and·capacitances
4216    ····//·Source-side·junction·currents
4217    ····T0··=·Vbs_jct·/·Nvtms;
4218    ····T1··=·lexp(T0)·-·1.0;
4219    ····T2··=·IVjsmRev·+·SslpRev·*·(Vbs_jct·-·VjsmRev);
4220    ····T3··=·T1·*·T2;
4221    ····T1··=·(BVS·+·Vbs_jct)·/·Nvtms;
4222    ····T2··=·lexp(-T1);
4223    ····T4··=·Isbs·*·(lexp(T0)·+·XExpBVS·-·1.0·-·XJBVS·*·T2);
4224    ····T5··=·IVjsmFwd·+·SslpFwd·*·(Vbs_jct·-·VjsmFwd);
4225
4226    ····if·(Isbs·>·0.0)·begin
4227    ····|···T6··=·T3·/·2.0·*·(1.0·-·tanh((Vbs_jct·-·VjsmRev)·/·Nvtms))·+·T4·/·2.0·*·(1.0·+·tanh((Vbs_jct·-·VjsmRev)·/·Nvtms));
4228    ····|···Ibs·=·T6·/·2.0·*·(1.0·-·tanh((Vbs_jct·-·VjsmFwd)·/·Nvtms))·+·T5·/·2.0·*·(1.0·+·tanh((Vbs_jct·-·VjsmFwd)·/·Nvtms));
4229    ····end·else·begin
4230    ····|···Ibs·=·0.0;
4231    ····end

4996    ····IBS···=·-devsign·*·MULT_I·*·Ibs;··//·Source·junction·current
```

- Similar changes are made to drain-side junction currents.

2. 2024bug19 (Infineon): devsign erroneously used in expansion effect model.

- Expansion effect modeling for pmos is not reasonable. This is due to the erroneous use of “devsign” in BSIM-BULK 107.2.0

BSIM-BULK 107.2.0

```
3868    ····|···|···|···idrift_sat_d·=·T11·*·NDRIFTD·*·T9·*·(1·+·devsign·*·CMD1·*·pow(Vb_cm,·CMD2));

3892    ····|···|···|···idrift_sat_s·=·T11·*·NDRIFTS·*·(1·+·devsign·*·CMS1·*·pow(Vb_cm,·CMS2));

4058    ····|···|···`Smooth(devsign·*·V(d,s)·-·DRII3·*·Vdseffii·-·DRII2··-·CMD1·*·devsign·*·pow(Vb_cm,·DRII4),·0.0,·0.05,·T2)
```

- In BSIM-BULK 107.2.1beta1, they are removed as follows.

BSIM-BULK 107.2.1beta1

```
3869    ····|···|···|···idrift_sat_d·=·T11·*·NDRIFTD·*·T9·*·(1·+·CMD1·*·pow(Vb_cm,·CMD2));

3893    ····|···|···|···idrift_sat_s·=·T11·*·NDRIFTS·*·(1·+·CMS1·*·pow(Vb_cm,·CMS2));

4060    ····|···|···`Smooth(devsign·*·V(d,s)·-·DRII3·*·Vdseffii·-·DRII2··-·CMD1·*·pow(Vb_cm,·DRII4),·0.0,·0.05,·T2)
```

3. 2024bug20 (Infineon): Expansion effect model impacts the non-expansion effect region.

- In BSIM-BULK 107.2.0, minimum value of Vb_cm is set to 1e-3. Therefore, Vb_cm will be approximately 1e-3 in non-expansion effect region. However, this value of 1e-3 can be large enough to increase the current significantly.

```
3866            Vb_cm = sqrt(V(bi,b) * V(bi,b) + 1.0e-6);
3867            if (IIMOD != 0) begin
3868                idrift_sat_d = T11 * NDRIFTD * T9 * (1 + devsign * CMD1 * pow(Vb_cm, CMD2));
3869            end else begin
3870                idrift_sat_d = T11 * NDRIFTD * T9;
3871            end
3890            Vb_cm = sqrt(V(bi,b) * V(bi,b) + 1.0e-6);
3891            if (IIMOD != 0) begin
3892                idrift_sat_s = T11 * NDRIFTS * (1 + devsign * CMS1 * pow(Vb_cm, CMS2));
3893            end else begin
3894                idrift_sat_s = T11 * NDRIFTS;
3895            end
4058        `Smooth(devsign * V(d,s) - DRII3 * Vdseffii - DRII2 - CMD1 * devsign * pow(Vb_cm, DRII4), 0.0, 0.05, T2)
```

BSIM-BULK 107.2.0

- In BSIM-BULK 107.2.1beta1, Vb_cm is modified. This reduces the current increase in non-expansion effect region down to 0.1%.

```
3867            if ((IIMOD != 0) && (CMD1>0)) begin
3868                Vb_cm = sqrt(V(bi,b) * V(bi,b) + pow(10, 2*(-3-log(CMD1))/CMD2));
3869                idrift_sat_d = T11 * NDRIFTD * T9 * (1 + CMD1 * pow(Vb_cm, CMD2));
3870            end else begin
3871                idrift_sat_d = T11 * NDRIFTD * T9;
3872            end
3891            if ((IIMOD != 0) && (CMS1>0)) begin
3892                Vb_cm = sqrt(V(bi,b) * V(bi,b) + pow(10, 2*(-3-log(CMS1))/CMS2));
3893                idrift_sat_s = T11 * NDRIFTS * (1 + CMS1 * pow(Vb_cm, CMS2));
3894            end else begin
3895                idrift_sat_s = T11 * NDRIFTS;
3896            end
4059        if (CMD1>0) begin
4060            `Smooth(devsign * V(d,s) - DRII3 * Vdseffii - DRII2 - CMD1 * pow(Vb_cm, DRII4), 0.0, 0.05, T2)
4061        end else begin
4062            `Smooth(devsign * V(d,s) - DRII3 * Vdseffii - DRII2, 0.0, 0.05, T2)
4063        end
```

BSIM-BULK 107.2.1beta1

4. 2024bug21 (Cadence): Discontinuity issue in the gmbs derivative.

- In BSIM-BULK 107.2.0 model, there is a discontinuity issue in the gmbs derivative.
- This problem is caused by the small delta_x value in the smooth function.
- In BSIM-BULK 107.2.1beta1 model, the delta_x value was changed from 5.0e-5 to 5.0e-3.

```
3443        // Vth shift for DIBL
3444        dVth_dibl = -(ETA0_a + ETAB_i * Vbsx) * Vdsx;
3445        `Smooth2(dVth_dibl, 0.0, 5.0e-5, dVth_dibl)
```

BSIM-BULK 107.2.0

```
3444      ····//·Vth·shift·for·DIBL
3445      ····dVth_dibl·=·-(ETA0_a·+·ETAB_i·*·Vbsx)·*·Vdsx;
3446      ····`Smooth2(dVth_dibl,·0.0,·5.0e-3,·dVth_dibl)
```

BSIM-BULK 107.2.1beta1