MVSG_CMC: V1.1.0

Updates from V1.0.0

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List of updates in V1.1.0 from V.1.0.0

The following updates and bug fixes have been made in V1.1.0 from the V1.0.0 release:

1. Two op-point additions
2. Source and drain terminal swapping correction for Source and drain access regions (SAR and DAR)
3. "Type" factor correction in access regions
4. Implementation of capacitive sub-circuit based g_m-dispersion models
5. OMI and aging parameter list

OP-point additions

Two op-points are added to the op-point list, namely:

1. Threshold voltage variable that accounts for drain-induced barrier lowering (DIBL): V_{tdibli}

$$V_{tdibli} = \boldsymbol{V_{t0}} - \left(\boldsymbol{\delta_1} - \frac{\boldsymbol{\delta_2}|V_{DS}|}{\left(1 + (\frac{|V_{DS}|}{\boldsymbol{DIBSAT}})^{\boldsymbol{\beta}}\right)^{1/\boldsymbol{\beta}}} \right) |V_{DS}|$$

2. The second parameter pertains to the drain-to-source saturation voltage V_{dsat1i} which governs the V_{DS} at the onset of drain-current saturation. This is given by:

$$V_{dsat1i} = V_{dsats1}(1 - FF) + 2\boldsymbol{n}\boldsymbol{\phi_T}FF \text{ where } V_{dsats1} = v_{x0}\boldsymbol{L}/\boldsymbol{\mu_0}[\sqrt{(1 + 2\frac{Q_{inv}}{C_g v_{x0}\boldsymbol{L}/\boldsymbol{\mu_0}})} - 1]$$

Changes in the code:

```
`OPP(vti,      "V",    "internal threshold voltage including DIBL")              Lines 604 and 605
`OPP(vdsati,   "V",    "internal drain-source saturation  voltage")
vti              = vtdibli;                                                       Lines 1015 and 1016
vdsati           = vdsat1i;
```

Terminal-voltage swapping in SAR and DAR [bug fix]

The V_{GS} and V_{GD} of SAR and DAR transistor elements are referenced to the lowest terminal voltage. This would be source-voltage (V_S) in forward mode and drain-voltage (V_D) in reverse mode. The referencing is necessary since the implicit-gate-voltage, V_{IG} is computed from surface-states that is referenced to vacuum-level as

$$\left(V_{IG} = \boldsymbol{V_{TOrs(d)}} + \frac{\mathbf{1}}{\boldsymbol{r_{sh}\, c_{grs(d)}\, mu_0}} \right)$$

From this equation, it is clear that the gate-voltage is not referenced to any-terminal voltage. Therefore the lowest-voltage-reference becomes necessary as it ensures relative terminal-voltage-computation for the access regions. This ensures that the scenarios of raising or lowering external terminal-voltages (V_D, V_G, V_S, V_B) by the same amount will have no impact on the device-currents. The following if-statements check the mode of operation:

Forward- or reverse-mode is checked: $if\ \left(\boldsymbol{type}\, V(src,d) \leq \boldsymbol{type}\, V(src,s)\right)$

V_{GS} assignment in forward-mode: $V_{gsrs} = V_{igs} - V(src,s)$

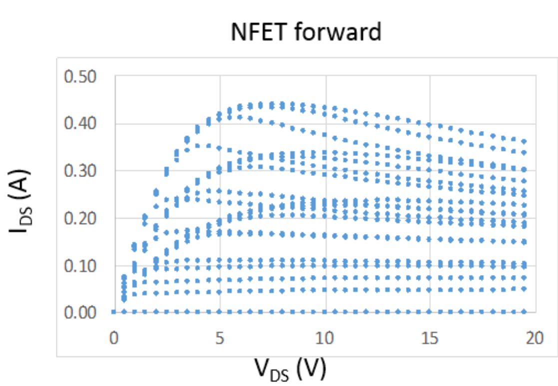
V_{GS} assignment in reverse-mode: $V_{gsrs} = V_{igs} - V(src,d)$

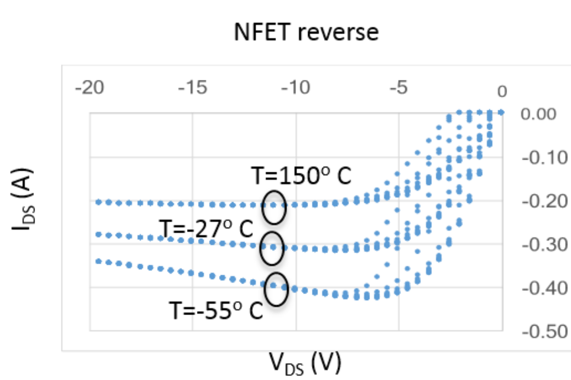
Changes in the code:

```
if  (type * V(src,d)<=  type * V(src,s))  begin
     vsars                   =  type * V(src,s);
end  else  begin
     vsars                   =  type * V(src,d);
end
vigs                         =  vtors  +  1.0  /  (rsh  *  cgrs * mu0);
vdsrs                        =  type * V(si,src);
vgsrs                        =  (vigs  -  vsars);
```

Lines 692 to 699 and 718 to 725

Impact on device characteristics:





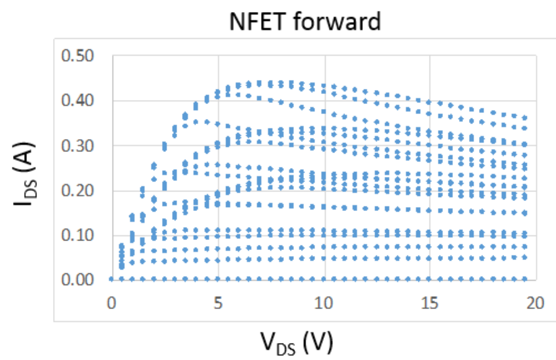
The bug-correction ensures I_{DS}-saturation in reverse mode, as can be seen in the figure.

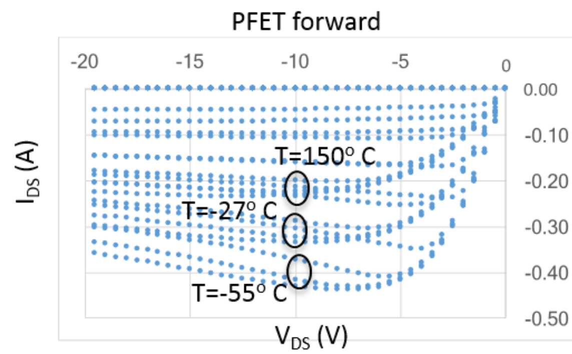
“Type” factor correction [bug-fix]

The parameter “type” is now included in the branch voltage assignment to access regions. The inclusion of the parameter in the computation of V_{DS}, V_{GS}, and V_{GD} of SAR and DAR transistors ensures the support of both N-type (electron-gas) and P-type (hole-gas) GaN HEMTs.

Example code-line in branch voltage assignment: $if\ \left(\boldsymbol{type}\ V(src,d) \leq \boldsymbol{type}\ V(src,s)\right)$

Impact on device characteristics:



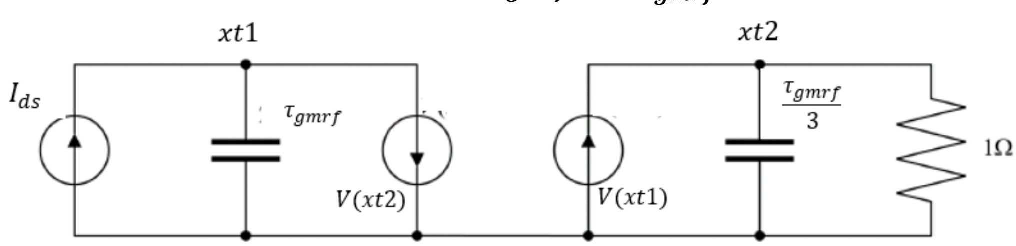


The changes give symmetric NFET and PFET behavior with sign-flipped for I_{DS} for V_{GS} and V_{DS} of same magnitudes and opposite signs.

Capacitive-implementation of g_m-dispersion model

The second-order transfer function of drain-current response to an RF-V_{GS} signal that incorporates dispersion (excess phase) effect is based on the sub-circuit shown and is given by:

$$I_{dsrf} = \frac{I_{ds}}{(1 + s\boldsymbol{\tau}_{\boldsymbol{gmrf}} + s^2\boldsymbol{\tau}_{\boldsymbol{gmrf}}^2/3)}$$



The two state-variables in the above expression can be expressed as a capacitive-resistive sub-circuit following the approach in [1] and computed as:

$$I_{ds} = I_{dsrf} + s\boldsymbol{\tau}_{\boldsymbol{gmrf}}\,(I_{dsrf} + s\boldsymbol{\tau}_{\boldsymbol{gmrf}} I_{dsrf}/3)$$
$$V(xt1) = \ (I_{dsrf} + s\boldsymbol{\tau}_{\boldsymbol{gmrf}} I_{dsrf}/3)$$
$$V(xt2) = I_{dsrf}$$

[1] McAndrew et. al., JSSC, 2009

Changes in the code:

```
idsrf                    = V(xt2);
 if (gmdisp==0) begin
V(xt1)       <+ 0;
V(xt2)       <+ 0;
I(di,si)          <+ ids + gmin * V(di,si);
 end else begin
I(xt1)     <+ ids - V(xt2) - ddt(taugmrf * V(xt1));
I(xt2)     <+ V(xt1) - V(xt2) - ddt((taugmrf/3.0) * V(xt2));
I(di,si)          <+ idsrf + gmin * V(di,si);
end
```

Lines 901 to 910

OMI parameter list

The following parameter list has been provided to include all possible aging effects.

```
// Model parameters
   `MPRoz(cg,          4.00e-03,  "F/m^2",     "Gate cap/area")
   `MPRcz(rsh,         150.0,     "Ohms/Sq",   "2-DEG Sheet Resistance")
   `MPRcz(rcs,         800e-6,    "Ohms*m",    "Source contact resistance * Width")
   `MPRcz(rcd,         800e-6,    "Ohms*m",    "Drain contact resistance * Width")
   `MPRoz(vx0,         3.0e5,     "m/s",       "Source injection velocity")
   `MPRoz(mu0,         0.135,     "m^2/Vs",    "Low-field mobility")
   `MPRnb(vto,         -2.72,     "V",         "Threshold voltage")
   `MPRoz(ss,          0.120,     "V/dec",     "Sub-threshold slope")
   `MPRcz(delta1,      16e-3,     "",          "DIBL Coefficient 1")
   `MPRcz(nd,          0.0,       "",          "Punchthrough factor for subth slope")

// Source access region parameters
   `MPRoz(cgrs,        5.0e-3,    "F/m^2",     "SAR gate-cap/area")
   `MPRoz(vx0rs,       100e3,     "m/s",       "SAR source injection velocity")
   `MPRoz(mu0rs,       100e-3,    "m^2/Vs",    "SAR low-field mobility")
   `MPRcz(delta1rs,    100e-3,    "",          "SAR DIBL Coefficient")
   `MPRoz(srs,         0.100,     "V/dec",     "SAR Sub-threshold slope")
   `MPRcz(ndrs,        0.0,       "",          "SAR punchthrough factor for subth slope")

// Drain access region parameters
   `MPRoz(cgrd,        4.3e-3,    "F/m^2",     "DAR gate-cap/area")
   `MPRoz(vx0rd,       100e3,     "m/s",       "DAR source injection velocity")
   `MPRoz(mu0rd,       100e-3,    "m^2/Vs",    "DAR low-field mobility")
   `MPRcz(delta1rd,    0.35,      "",          "DAR DIBL Coefficient")
   `MPRoz(srd,         0.3,       "V/dec",     "DAR Sub-threshold slope")
   `MPRcz(ndrd,        3.8,       "",          "DAR punchthrough factor for subth slope")

// Field-Plate 1 parameters
   `MPRnb(vtofp1,      -44.5,     "V",         "FP threshold voltage")
   `MPRoz(cgfp1,       2.0e-4,    "F/m^2",     "FP gate-cap/area")
   `MPRoz(vx0fp1,      1.2e5,     "m/s",       "FP source injection velocity")
   `MPRoz(mu0fp1,      0.2,       "m^2/Vs",    "FP low-field mobility")
   `MPRcz(delta1fp1,   0.0,       "",          "FP DIBL Coefficient")
   `MPRoz(sfp1,        3.2,       "V/dec",     "FP Sub-threshold slope")
   `MPRcz(ndfp1,       0.0,       "",          "FP punchthrough factor for subth slope")

// Field-Plate 2 parameters
   `MPRnb(vtofp2,      -74.5,     "V",         "FP threshold voltage")
   `MPRoz(cgfp2,       1.0e-4,    "F/m^2",     "FP gate-cap/area")
   `MPRoz(vx0fp2,      1.2e5,     "m/s",       "FP source injection velocity")
```

```
    `MPRoz(mu0fp2,      0.2,        "m^2/Vs",   "FP low-field mobility")
    `MPRcz(delta1fp2,   0.0,        "",         "FP DIBL Coefficient")
    `MPRoz(sfp2,        3.2,        "V/dec",    "FP Sub-threshold slope")
    `MPRcz(ndfp2,       0.0,        "",         "FP punchthrough factor for subth slope")

// Field-Plate 3 parameters
    `MPRnb(vtofp3,      -44.5,      "V",        "FP threshold voltage")
    `MPRoz(cgfp3,       2.0e-4,     "F/m^2",    "FP gate-cap/area")
    `MPRoz(vx0fp3,      1.2e5,      "m/s",      "FP source injection velocity")
    `MPRoz(mu0fp3,      0.2,        "m^2/Vs",   "FP low-field mobility")
    `MPRcz(delta1fp3,   0.0,        "",         "FP DIBL Coefficient")
    `MPRoz(sfp3,        3.2,        "V/dec",    "FP Sub-threshold slope")
    `MPRcz(ndfp3,       0.0,        "",         "FP punchthrough factor for subth slope")

// Field-Plate 4 parameters
    `MPRnb(vtofp4,      -44.5,      "V",        "FP threshold voltage")
    `MPRoz(cgfp4,       2.0e-4,     "F/m^2",    "FP gate-cap/area")
    `MPRoz(vx0fp4,      1.2e5,      "m/s",      "FP source injection velocity")
    `MPRoz(mu0fp4,      0.2,        "m^2/Vs",   "FP low-field mobility")
    `MPRcz(delta1fp4,   0.0,        "",         "FP DIBL Coefficient")
    `MPRoz(sfp4,        3.2,        "V/dec",    "FP Sub-threshold slope")
    `MPRcz(ndfp4,       0.0,        "",         "FP punchthrough factor for subth slope")

// Gate leakage parameter
    `MPRcz(pg_params,   1.00,       "1/V",      "G-S something like 1/eta*Vt")
    `MPRcz(ijs,         1.00e-12,   "A/m",      "G-S reverse leakage current normalized to width")
    `MPRcz(pg_paramd,   1.00,       "1/V",      "G-D something like 1/eta*Vt")
    `MPRcz(ijd,         1.00e-12,   "A/m",      "G-D reverse leakage current normalized to width")

    `MPRcz(pgsrecs,     0.5,        "",         "G-S something like 1/eta for reverse recombination")
    `MPRcz(irecs,       1.0e-18,    "A/m",      "G-S reverse leakage current normalized to width")
    `MPRcz(pgsrecd,     0.8,        "",         "G-D something like 1/eta for reverse recombination")
    `MPRcz(irecd,       2e-5,       "A/m",      "G-D reverse leakage current normalized to width")

// Trapping model parameters for Ron increase
    `MPRcz(vttrap,      230,        "V",        "Trapping stress threshold voltage")
    `MPRcz(taut,        3e-5,       "s",        "Trap time constant")
    `MPRcz(alphat1,     1e-4,       "",         "Trap coefficient 1 on bias stress")
    `MPRoz(alphat2,     21,         "V",        "Trap coefficient 2 on bias stress")

// Noise model parameters
    `MPRcz(shs,         3.0,        "",         "G-S shot noise parameter")
    `MPRcz(shd,         3.0,        "",         "G-D shot noise parameter")
    `MPRcz(kf,          1.0e-4,     "",         "Flicker noise coefficient")
```


Acknowledgements

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