N Channel MOSFET level 1 mosn1

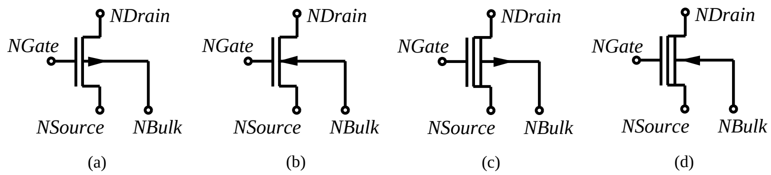

Figure 1: N Channel MOSFET Level 1 model

Form:

`mosn1`:⟨`instance name`⟩ n_1 n_2 n_3 n_4 ⟨`parameter list`⟩

instance name	is the model name,
n_1	is the drain node,
n_2	is the gate node,
n_3	is the source node,
n_4	is the bulk node.

Parameters:

Parameter	Type	Default value	Required?
vt0: Zero bias threshold voltage (V)	DOUBLE	0	no
kp: Transconductance parameter (A/V^2)	DOUBLE	2×10^{-5}	no
gamma: Bulk threshold parameter (V$^{0.5}$)	DOUBLE	0	no
phi: Surface inversion potential (V)	DOUBLE	0.6	no
lambda: Channel-length modulation (1/V)	DOUBLE	0	no
pb: Bulk junction potential (V)	DOUBLE	0.8	no
tox: Oxide thickness (m)	DOUBLE	1×10^{-7}	no
ld: Lateral diffusion length (m)	DOUBLE	0	no
u0: Surface mobility (cm^2/V-s)	DOUBLE	600	no
fc: Forward bias junction fit parameter	DOUBLE	0.5	no
nsub: Substrate doping (cm^{-3})	DOUBLE	1×10^{15}	no
tpg: Gate material type	DOUBLE	1	no
nss: Surface state density (cm^{-2})	DOUBLE	0	no
tnom: Nominal temperature (C)	DOUBLE	27	no
t: Device temperature (C)	DOUBLE	27	no
l: Device length (m)	DOUBLE	2×10^{-6}	no
w: Device width (m)	DOUBLE	50×10^{-6}	no
alpha: Impact ionization current coefficient	DOUBLE	0	no

Example:

```
mosn1:m1 2 3 0 0 l=1.2u w=20u
```

Description:
FreeDa has the NMOS level 1 model based on the MOS level 1, Schichman-Hodges model in SPICE. The model uses the charge conservative Yang-Chatterjee model for modeling charge and capacitance.

The physical constants used in the model evaluation are

k	Boltzmann's constant	$1.3806226\,10^{-23}$ J/K
q	electronic charge	$1.6021918\,10^{-19}$ C
ϵ_0	free space permittivity	$8.854214871\,10^{-12}$ F/m
ϵ_{Si}	permittivity of silicon	$11.7\epsilon_0$
ϵ_{OX}	permittivity of silicon dioxide	$3.9\epsilon_0$
n_i	intrinsic concentration of silicon @ 300 K	$1.45\,10^{16}$ m^{-3}

Standard Calculations

Absolute temperatures (in kelvins, K) are used. The thermal voltage

$$V_{TH}(T_{NOM}) = \frac{kT_{NOM}}{q}. \tag{1}$$

The silicon bandgap energy

$$E_G(T_{NOM}) = 1.16 - 0.000702\frac{4T_{NOM}^2}{T_{NOM} + 1108}. \tag{2}$$

The difference of the gate and bulk contact potentials

$$\phi_{\mathtt{MS}} = \phi_{GATE} - \phi_{BULK}. \tag{3}$$

The gate contact potential

$$\phi_{GATE} = \begin{cases} 3.2 & T_{PG} = 0 \\ 3.25 & \text{NMOS \& } T_{PG} = 1 \\ 3.25 + E_G & \text{NMOS \& } T_{PG} = -1 \end{cases}. \tag{4}$$

The contact potential of the bulk material

$$\phi_{BULK} = 3.25 + E_G \quad \text{for NMOS} \tag{5}$$

The capacitance per unit area of the oxide is

$$C_{OX} = \frac{\epsilon_{OX}}{\mathtt{TOX}}. \tag{6}$$

The effective length L_{EFF} of the channel is reduced by the amount `LD` of the lateral diffusion at the source and drain regions:

$$L_{EFF} = \mathtt{L} - 2\mathtt{LD} \tag{7}$$

Similarly the effective length W_{EFF} of the channel is reduced by the amount `WD` of the lateral diffusion at the edges of the channel.

$$W_{EFF} = \mathtt{W} - 2\mathtt{WD} \tag{8}$$

Process Oriented Model

If omitted, device parameters are computed from process parameters using defaults if necessary provided that both `TOX` and `NSUB` are specified. If either `TOX` or `NSUB` is not specified then the critical device parameters must be specified.

If `KP` is not specified in the model statement then

$$\mathtt{KP} = \mu_0 / C_{OX} \tag{9}$$

If `PHI` is not specified, then it is evaluated as

$$\mathtt{PHI} = 2\phi_B = 2V_{TH}(T_{NOM}) \ln \frac{\mathtt{NSUB}}{n_i} \tag{10}$$

If `GAMMA` is not specified in the model statement then

$$\mathtt{GAMMA} = \gamma = \frac{\sqrt{2\epsilon_{Si} q NSUB}}{C_{OX}} \tag{11}$$

If `VTO` is not specified in the model statement then it is evaluated as

$$\mathtt{VTO} = V_{FB} + \gamma\sqrt{2\phi_B} + 2\phi_B \tag{12}$$

where V_{FB} is

$$V_{FB} = \phi_{MS} - \frac{q\ \mathtt{NSS}}{\mathtt{C_{OX}}} \tag{13}$$

Temperature Dependence

Temperature effects are incorporated as follows where T and $T_{\mathtt{NOM}}$ are absolute temperatures in Kelvins (K).

$$\begin{aligned}
V_{TH} &= \frac{kT}{q} && (14)\\
KP(T) &= \mathtt{KP}(T_{NOM}/T)^{3/2} && (15)\\
\mu(T) &= \mu_0(T_{NOM}/T)^{3/2} && (16)\\
2\phi_B(T) &= 2\phi_B \frac{T}{T_{NOM}} - 3V_{TH} \ln \frac{T}{T_{NOM}} + E_G(T_{NOM} - E_G(T) && (17)
\end{aligned}$$

DC Current Calculations

The Schichman-Hodges model computes the current of the MOS device in only three regions, cutoff, linear and saturation. The regions are defined as:

cutoff region:	$V_{GS} < V_T$
linear region:	$V_{GS} > V_T$ and $V_{DS} < V_{GS} - V_T$
saturation region:	$V_{GS} > V_T$ and $V_{DS} > V_{GS} - V_T$

where the threshold voltage is

$$V_T = \begin{cases} V_{FB} + 2\phi_B + \gamma\sqrt{2\phi_B - V_{BS}} & V_{BS} \geq 2\phi_B \\ V_{FB} + 2\phi_B & V_{BS} < 2\phi_B \end{cases} \tag{18}$$

Then

$$I_D = \begin{cases} 0 & \text{cutoff region} \\ \frac{W_{EFF}}{L_{EFF}} \frac{KP}{2} (1 + \lambda V_{DS}) V_{DS} \left[2(V_{GS} - V_T) - V_{DS}\right] & \text{linear region} \\ \frac{W_{EFF}}{L_{EFF}} \frac{KP}{2} (1 + \lambda V_{DS}) \left[V_{GS} - V_T\right]^2 & \text{saturation region} \end{cases} \tag{19}$$

Yang-Chatterjee ChargeModel

Once the DC channel current has been calculated, the charge at each terminal of the MOS device is computed. The charge values are used to compute the AC current flow through each terminal according to the Yang-Chatterjee model. This model ensures continuity of the charges and capacitances throughout different regions of operation. The intermediate quantities are:

$$V_{FB} = V_{to} - \gamma\sqrt{2\phi_B} - 2\phi_B \tag{20}$$

and

$$C_o = C_{OX}\, W_{eff}\, L_{eff} \tag{21}$$

The charge is computed for for each of the four regions of operation, accumulation, cut-off, saturation and linear.

Accumulation region $V_{GS} \leq V_{FB} + V_{BS}$

$$Q_d = 0 \tag{22}$$

$$Q_s = 0 \tag{23}$$

$$Q_b = -C_o\,(V_{GS} - V_{FB} - V_{BS}) \tag{24}$$

Cut-off region $V_{FB} + V_{BS} < V_{GS} \leq V_{th}$

$$Q_d = 0 \quad (25)$$

$$Q_s = 0 \quad (26)$$

$$Q_b = -C_o \frac{\mathtt{GAMMA}^2}{2} \{-1 + \sqrt{1 + \frac{4\,(V_{GS} - V_{FB} - V_{BS})}{\mathtt{GAMMA}^2}}\} \quad (27)$$

Saturation region $V_{th} < V_{GS} \leq V_{DS} + V_{th}$

$$Q_d = 0 \quad (28)$$

$$Q_s = -\frac{2}{3}\,C_o\,(V_{GS} - V_{th}) \quad (29)$$

$$Q_b = C_o\,(V_{FB}\,\mathtt{PHI} - V_{th}) \quad (30)$$

Linear region $V_{GS} > V_{DS} + V_{th}$

$$Q_d = -C_o\,[\frac{V_{DS}^2}{8\,(V_{GS} - V_{th} - \frac{V_{DS}}{2})} + \frac{V_{GS} - V_{th}}{2} - \frac{3}{4}\,V_{DS}] \quad (31)$$

$$Q_s = -C_o\,[\frac{V_{DS}^2}{24\,(V_{GS} - V_{th} - \frac{V_{DS}}{2})} + \frac{V_{GS} - V_{th}}{2} + \frac{1}{4}\,V_{DS}] \quad (32)$$

$$Q_b = C_o\,(V_{FB}\,\mathtt{PHI} - V_{th}) \quad (33)$$

The final currents at the transistor nodes are given by

$$I_d = I_D + \frac{dQ_d}{dt} \quad (34)$$

$$I_g = \frac{dQ_g}{dt} \quad (35)$$

$$I_s = -I_D + \frac{dQ_s}{dt} \quad (36)$$

Notes:
This is the `M` element in the SPICE compatible netlist. The unmodified Yang-Chatterjee charge model has a charge partition scheme in the saturation region that sets the drain charge to zero. This results in a loss of the high-frequency current roll-off at the drain node in saturation.

Credits:

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