Chapter 12: Temperature Dependence Model

Accurate modeling of the temperature effects on MOSFET characteristics is important to predict circuit behavior over a range of operating temperatures (*T*). The operating temperature might be different from the nominal temperature (*TNOM*) at which the BSIM4 model parameters are extracted. This chapter presents the BSIM4 temperature dependence models for threshold voltage, mobility, saturation velocity, source/drain resistance, and junction diode IV and CV.

12.1 Temperature Dependence of Threshold Voltage

The temperature dependence of V_{th} is modeled by

(12.1.1)

$$V_{th}(T)=V_{th}(TNOM)+\left(KT1+\frac{KT1L}{L_{eff}}+KT2\cdot V_{bseff}\right)\cdot\left(\frac{T}{TNOM}-1\right)$$

12.2 Temperature Dependence of Mobility

The BSIM4 mobility model parameters have the following temperature dependences

(12.2.1)

$$U0(T) = U0(TNOM) \cdot (T/TNOM)^{UTE}$$

(12.2.2)

$$UA(T) = UA(TNOM) + UA1 \cdot (T/TNOM - 1)$$

(12.2.3)

$$UB(T) = UB(TNOM) + UB1 \cdot (T/TNOM - 1)$$

and

(12.2.4)

$$UC(T) = UC(TNOM) + UC1 \cdot (T/TNOM - 1)$$

12.3 Temperature Dependence of Saturation Velocity

The temperature dependence of *VSAT* is modeled by

(12.3.1)

$$VSAT(T) = VSAT(TNOM) - AT \cdot (T/TNOM - 1)$$

12.4 Temperature Dependence of LDD Resistance

- ***rdsMod* = 0 (internal source/drain LDD resistance)**

(12.4.1)

$$RDSW(T) = RDSW(TNOM) + PRT \cdot (T/TNOM - 1)$$

(12.4.2)

$$RDSWMIN(T) = RDSWMIN(TNOM) + PRT \cdot (T/TNOM - 1)$$

- ***rdsMod* = 1 (external source/drain LDD resistance)**

(12.4.3)

$$RDW(T) = RDW(TNOM) + PRT \cdot (T/TNOM - 1)$$

(12.4.4)

$$RDWMIN(T) = RDWMIN(TNOM) + PRT \cdot (T/TNOM - 1)$$

(12.4.5)

$$RSW(T) = RSW(TNOM) + PRT \cdot (T/TNOM - 1)$$

and

(12.4.6)

$$RSWMIN(T) = RSWMIN(TNOM) + PRT \cdot (T/TNOM - 1)$$

12.5 Temperature Dependence of Junction Diode IV

- **Source-side diode**

The source-side saturation current is given by

(12.5.1)

$$I_{sbs} = A_{seff} J_{ss}(T) + P_{seff} J_{ssws}(T) + W_{effcj} \cdot NF \cdot J_{sswgs}(T)$$

where

(12.5.2)

$$J_{ss}(T) = JSS(TNOM) \cdot \exp\left(\frac{\frac{E_g(TNOM)}{v_t(TNOM)} - \frac{E_g(T)}{v_t(T)} + XTIS \cdot \ln\left(\frac{T}{TNOM}\right)}{NJS} \right)$$

(12.5.3)

$$J_{ssws}(T) = JSSWS(TNOM) \cdot \exp\left(\frac{\frac{E_g(TNOM)}{v_t(TNOM)} - \frac{E_g(T)}{v_t(T)} + XTIS \cdot \ln\left(\frac{T}{TNOM}\right)}{NJS} \right)$$

and

(12.5.4)

$$J_{sswgs}(T) = JSSWGS(TNOM) \cdot \exp\left(\frac{\frac{E_g(TNOM)}{v_t(TNOM)} - \frac{E_g(T)}{v_t(T)} + XTIS \cdot \ln\left(\frac{T}{TNOM}\right)}{NJS} \right)$$

where E_g is given in Section 12.7.

- **Drain-side diode**

The drain-side saturation current is given by

(12.5.5)

$$I_{sbd} = A_{deff} J_{sd}(T) + P_{deff} J_{sswd}(T) + W_{effcj} \cdot NF \cdot J_{sswgd}(T)$$

where

(12.5.6)

$$J_{sd}(T) = JSD(TNOM) \cdot \exp\left(\frac{\frac{E_g(TNOM)}{v_t(TNOM)} - \frac{E_g(T)}{v_t(T)} + XTID \cdot \ln\left(\frac{T}{TNOM}\right)}{NJD} \right)$$

(12.5.7)

$$J_{sswd}(T) = JSSWD(TNOM) \cdot \exp\left(\frac{\frac{E_g(TNOM)}{v_t(TNOM)} - \frac{E_g(T)}{v_t(T)} + XTID \cdot \ln\left(\frac{T}{TNOM}\right)}{NJD} \right)$$

and

(12.5.8)

$$J_{sswgd}(T) = JSSWGD(TNOM) \cdot \exp\left(\frac{\frac{E_g(TNOM)}{v_t(TNOM)} - \frac{E_g(T)}{v_t(T)} + XTID \cdot \ln\left(\frac{T}{TNOM}\right)}{NJD} \right)$$

12.6 Temperature Dependence of Junction Diode CV

- **Source-side diode**

The temperature dependences of zero-bias unit-length/area junction capacitances on the source side are modeled by

(12.6.1)

$$CJS(T) = CJS(TNOM) \cdot [1 + TCJ \cdot (T - TNOM)]$$

(12.6.2)

$$CJSWS(T) = CJSWS(TNOM) + TCJSW \cdot (T - TNOM)$$

and

(12.6.3)

$$CJSWGS(T) = CJSWGS(TNOM) \cdot [1 + TCJSWG \cdot (T - TNOM)]$$

The temperature dependences of the built-in potentials on the source side are modeled by

(12.6.4)

$$PBS(T) = PBS(TNOM) - TPB \cdot (T - TNOM)$$

(12.6.5)

$$PBSWS(T) = PBSWS(TNOM) - TPBSW \cdot (T - TNOM)$$

and

(12.6.6)

$$PBSWGS(T) = PBSWGS(TNOM) - TPBSWG \cdot (T - TNOM)$$

- **Drain-side diode**

The temperature dependences of zero-bias unit-length/area junction capacitances on the drain side are modeled by

(12.6.7)

$$CJD(T) = CJD(TNOM) \cdot [1 + TCJ \cdot (T - TNOM)]$$

(12.6.8)

$$CJSWD(T) = CJSWD(TNOM) + TCJSW \cdot (T - TNOM)$$

and

(12.6.9)

$$CJSWGD(T) = CJSWGD(TNOM) \cdot [1 + TCJSWG \cdot (T - TNOM)]$$

The temperature dependences of the built-in potentials on the drain side are modeled by

(12.6.10)

$$PBD(T) = PBD(TNOM) - TPB \cdot (T - TNOM)$$

(12.6.11)

$$PBSWD(T) = PBSWD(TNOM) - TPBSW \cdot (T - TNOM)$$

and

(12.6.12)

$$PBSWGD(T) = PBSWGD(TNOM) - TPBSWG \cdot (T - TNOM)$$

12.7 Temperature Dependences of E_g and n_i

- **Energy-band gap of Si (E_g)**

The temperature dependence of E_g is modeled by

(12.7.1)

$$E_g(TNOM) = 1.16 - \frac{7.02 \times 10^{-4} TNOM^2}{TNOM + 1108}$$

and

(12.7.2)

$$E_g(T) = 1.16 - \frac{7.02 \times 10^{-4} T^2}{T + 1108}$$

- **Intrinsic carrier concentration of Si (n_i)**

The temperature dependence of n_i is modeled by

(12.7.3)

$$n_i = 1.45e10 \cdot \frac{TNOM}{300.15} \cdot \sqrt{\frac{TNOM}{300.15}} \cdot \exp\left[21.5565981 - \frac{qE_g(TNOM)}{2 \cdot k_B T}\right]$$