

Temperature Dependency of MOSFET Device Characteristics in 4H- and 6H-Silicon Carbide (SiC)

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An analytical model for lateral MOSFET that includes the effects of temperature variation in 4H- and 6H-SiC poly-type is presented in this paper. SiC shows a tremendous potential for high temperature electronics applications [1-4]. The model includes the effects of temperature variation on the threshold voltage, the carrier mobility, the body leakage current, and the drain and source contact region resistances. The model is validated for 6H-SiC by comparing simulation results with previously measured experimental data reported in [5]. MOSFET device behavior in 4H-SiC is also simulated and compared with 6H-SiC material system.

A large-signal model for lateral MOSFET with temperature compensation is shown in Figure 1. The compensating currents contribute to the total current at high temperature. The three compensating current elements are; (i) the body leakage current, I_R (ii) the current change due to the threshold voltage change, I_{TH} (iii) the current change due to the change of drain and source contact region resistance, I_{RDS} . Room temperature (300°K) has been taken as the reference temperature. MOSFET channel current, I_D has been calculated at room temperature using MOSFET charge sheet model [6]. Channel current, I_D is kept constant for all temperature. The compensating currents incorporate the change in MOSFETs current.

The total drain current, which is reported in [7] can be expressed by equation (1) as;

$$I_{total} = I_D + I_R + I_{TH} + I_{RDS} \quad (1)$$

$$\text{where } I_R = qA \frac{D_n n_i^2}{L_n N_A} \alpha A T^3 \exp\left\{-\frac{E_g}{kT}\right\} \quad (2)$$

$$I_{TH} = \frac{W}{L} \mu_n C_{ox} [V'_{TH} - V_{TH}] V_{DS} \quad (3)$$

$$I_{TH_{sat}} = \frac{W}{2L} \mu_n C_{ox} [(V_{GS} - V'_{TH})^2 - (V_{GS} - V_{TH})^2] \quad (4)$$

$$I_{RDS} = \beta \left(\frac{1}{R'_{DS}} - \frac{1}{R_{DS}} \right) V_{DS} \quad (5)$$

At room temperature, I_R is negligible; I_{TH} and I_{RDS} become zero. However, with the increase in temperature, compensating terms contribute to the total current.

The simulation results in 6H-SiC (Figure 2 and 3) match very well with the measured data at 300°K as compared to the results at 600°K where there are minor discrepancies. At 300°K, the drain current is 15μA, whereas it rises to 235μA at 600°K for a gate voltage $V_{GS}=6V$. At room temperature, the current starts conducting through the channel at a gate voltage of $V_{GS}=3.2V$, whereas it starts at $V_{GS}=1.2V$ at 600°K. Thus, the threshold voltage changes from 3.2V at 300°K to 1.2V at 600°K. It is observed that most of the current change (about 85% on an average) is obtained by threshold voltage change i.e. threshold voltage mostly characterizes the device behavior.

The model is also used to simulate the device characteristics in 4H-SiC material system. Since the model showed a good agreement with measured data for 6H-SiC, simulation results for 4H-SiC is also reasonable and acceptable for prediction of device behavior in 4H-SiC. Figure 4 and 5 shows the comparison of output characteristics of 4H- and 6H-SiC MOSFET at 300°K and transfer

characteristics at different temperature, respectively. Simulation results show that the drain currents of 4H-SiC MOSFET are greater than that of 6H-SiC counterpart by a factor of approximately two. This could be attributed to higher mobility values of 4H-SiC inversion layer ($\cong 40 \text{ cm}^2/\text{V}\cdot\text{sec}$) compared to that of 6H-SiC ($\cong 20 \text{ cm}^2/\text{V}\cdot\text{sec}$). In summary, 4H-SiC material system provides enhanced device performance compared to 6H-SiC counterpart.

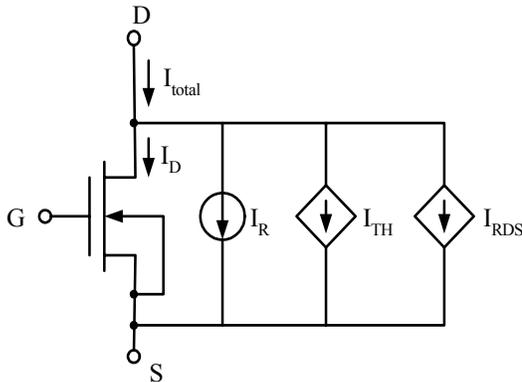


Figure 1: MOSFET model with temperature compensation

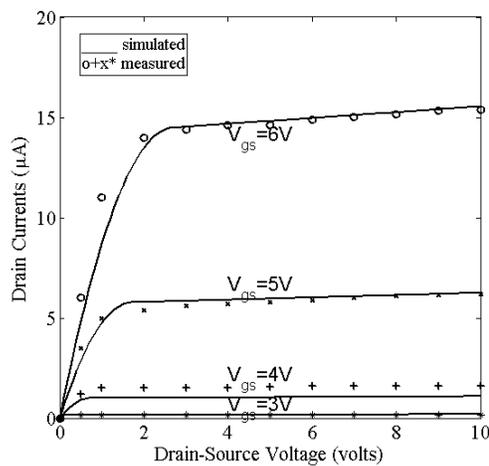


Figure 2: Simulated and measured currents at 300°K

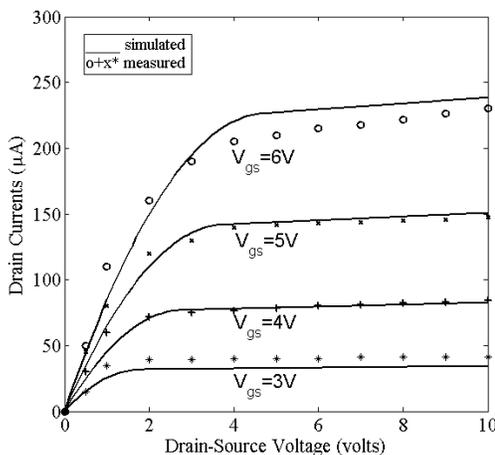


Figure 3: Simulated and measured currents at 600°K

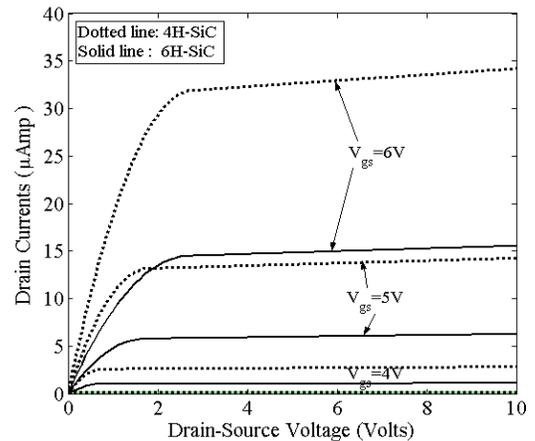


Figure 4: Output characteristics of 4H- & 6H-SiC lateral MOSFET

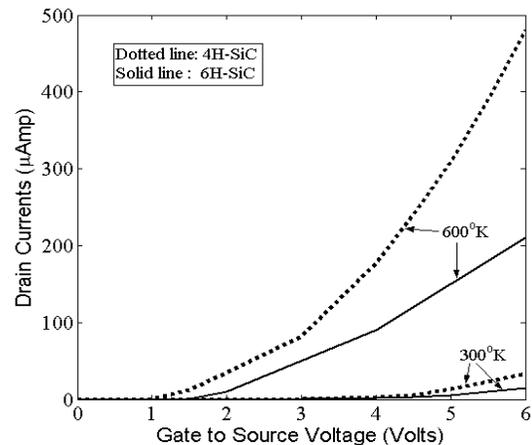


Figure 5: Transfer characteristics of 4H- & 6H-SiC lateral MOSFET

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