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Research Article

MOSiC (3C, 4H and 6H) Transistors 130nm by BSIM3v3 Model in Low Voltage and Low Power

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Abstract

Silicon carbide is a very interesting semiconductor for applications in high temperature, high frequency and high power. In this article, we have studied and compared MOS transistors with 130nm silicon carbide (3C-SiC, 4H-SiC and 6H-SiC) technologies using BSIM3v3 model. To perform this work we have used PSpice to study the characteristics I(V) and the transconductance gm as a function of temperature in the range -200° C to 750° C with a supply voltage VDS = 1.2V. We have also calculated the transition frequencies fT of the three types of transistors. Our results show that the (3C, 4H and 6H)-SiC transistors operate under a low voltage, low power, high temperature and high frequency in submicron dimension.

Keywords: 3C-SiC, 4H-SiC, 6H-SiC, BSIM3v3, MOSFET

1. Introduction

Silicon carbide is a wide bandgap semiconductor. It has a high breakdown field, a high saturation velocity of electrons and a high thermal conductivity [01]. This semiconductor is generally used to manufacture electronic components which support high voltages and powers [02]. In our work, we will use BSIM3v3 as model for our silicon carbide transistors (3C-SiC, 4H-SiC and 6H-SiC). Based on the equations of this model [03-04], we will calculate our components, then simulate their characteristics $I_D = f\ (V_{DS})$, the transfer $I_D = f\ (V_{GS})$ and transconductance $g_m=f(T)$. Our work will be carried for 130nm channel length, 1.2V supply voltage and temperatures between -200°C and 750°C. We will use the small signal equivalent circuit for a MOSFET, to determine the transition frequencies f_T of different devices.

2. Description of the transistor

To realize a comparison, we use a same structure for different MOS transistors in technologies 3C-SiC, 4H-SiC and 6H-SiC (Fig- 1).

In order to perform a comparison between different transistors, we will calculate their PSpice parameters taking the same structure for each one (dimensions and doping), as it is shown in table- 1.

3. Simulation results and discussion

3.1 Output characteristics $I_D = f\ (V_{DS})$

To characterize the three NMOSiC transistors in direct polarization mode, we have applied a voltage V_{GS} of 1.2V and varied V_{DS} from 0 to 1.2V with 0.2V step .The voltaje values of V_{DS} were chosen so as to distinguish the two regions of operation (linear and saturation). After simulation, we obtained the characteristics of Fig- 2.

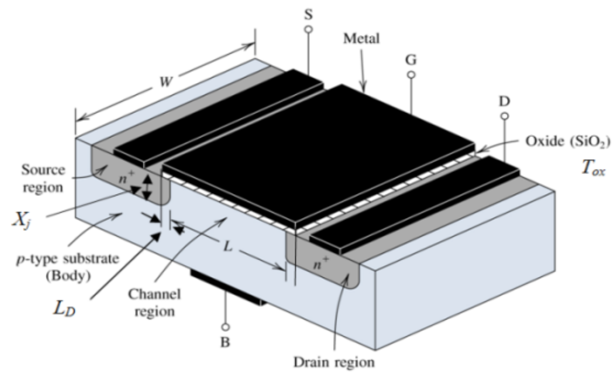

Fig. 1. Structure used of MOSiC transistors.

Fig- 2 shows that the two functional parts of our three transistors are distinct. Ohmic parte (linear) is located for V_{DS} below 0.6V for 4H-SiC and 6H-SiC based transistors, however for 3C-SiC transistor, it is up to 1V. The SiC based transistors designed for high voltages and high powers may function well at low voltages and low powers. The 3C-SiC transistor is characterized by a drain current 5 times greater than that of 6H-SiC transistor and 15 times greater than that of 4H-SiC transistor.

For BSIM3v3 model the drain current can be expressed as [03]:

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$$I_{DS} = \frac{\mu_{eff} C_{ox} W E_{sat}}{E_{sat} L + V_{DS}} \left(V_{gs} - V_{th} - \frac{A_{bulk} V_{DS}}{2}\right) V_{DS} = a \left(V_{gs} - V_{th} - \frac{A_{bulk} V_{DS}}{2}\right) V_{DS} \quad (1)$$

Table 1. Control parameters of the model.

Parameters	Description	values
Level	Level model selector	7
Version	Model version number	3.2
MobMod	Mobility model selector	1
CapMod	Flag for the short channel capacitance model	3
T_{ox}	Gate oxide thickness (m)	2.5E-9
X_j	Junction Depth (m)	1E-7
X_t	Doping depth (m)	1.05E-7
Ng=Nd=Ns	Gate, Drain and source doping concentration (cm^{-3})	1E20
Nsub	Substrate doping concentration (cm^{-3})	6E17
N_{ch}	Channel doping concentration (cm^{-3})	2.36E17
VBM	Maximum applied body bias in Vth calculation	-3
L	Channel length (nm)	130
W	Channel width (nm)	160

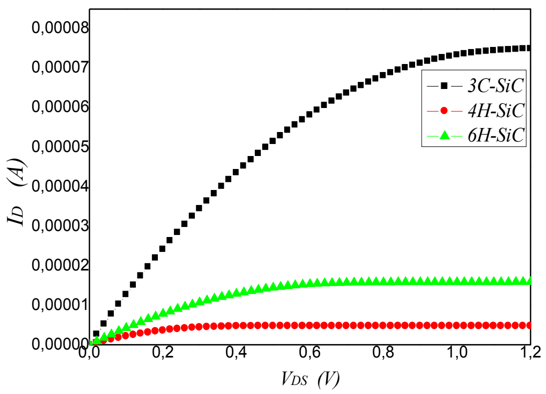

Fig. 2. Output Characteristics I_D=f(V_{DS}) of NMOSiC transistors.

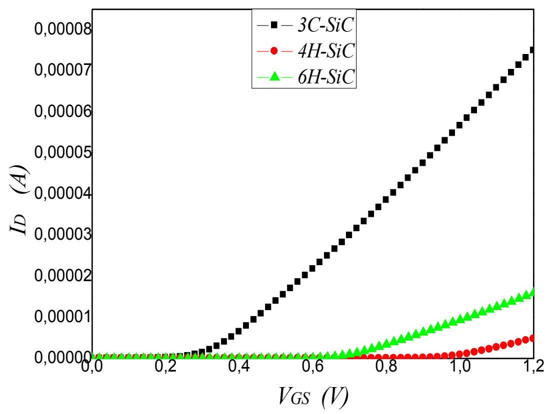

Fig. 3. Transfer characteristic I_D = f (V_{GS}) of the NMOSiC transistors.

The geometric structure and oxide type used is the same for the three NMOSiC transistors. The ratio ***a*** is approximately the same for different transistors. Drain current is inversely proportional to the threshold voltage.

Where the threshold voltage V_{th} increases, the expression $\left(V_{gs} - V_{th} - \frac{A_{bulk} V_{DS}}{2}\right)$ decreases and as in SiC technology, $V_{th\,(3C-SiC)} < V_{th(6H-SiC)} < V_{th(4H-SiC)}$,the drain current of 3C-SiC transistor is greater than the others, as it is illustrated in Figure 2. From our results, we conclude that the 4H-SiC transistor technology is characterized by a low power compared to others (MO(3C-SiC) and MO(6H-SiC)) transistors. The band-gap narrowing principle [05-06-07-08]. Submicron technology and charge carriers concentration are directly responsible of the operation of our transistors at low voltage and low power. Based on our results, we conclude that the 4H-SiC transistor is characterized by a low power compared to the other MO (3C-SiC) and MO (6H-SiC) transistors.

3.2 Transfer characteristics $I_D = f\ (V_{GS})$

For the simulation of transfer characteristics I_D = f (V_{GS}) for NMOSiC transistors we have applied a voltage V_{DS} = 1.2V, and we varied the V_{GS} voltage from 0V to 1.2V. The results of our simulation are presented in Fig- 3.

4H-SiC NMOS transistor is characterized by a high value of threshold voltage compared to 6H-SiC transistor, and the latter has a threshold voltage higher than the 3C-SiC transistor.

The geometric structure, oxide type used and doping technology are the same for different MOSiC transistors.

The parameters which influence the evolution of threshold voltage of the different MOS transistors by considering BSIM3v3 model (expression 1) [04] are: the carrier concentration **n** and the gap **Eg** of each semiconductor.

- Once the gap of semiconductor increases, threshold voltage also increases.
- Once the carrier concentration increases, threshold voltage decreases.

The electrical characteristics (I_D = f (V_{DS}) and I_D = f (V_{GS})) of our transistors in 4H-SiC and 6H-SiC technology, are similar to those obtained by Md Hasanuzzaman [09] and Vickram R. [10], but there is a contradiction between our result and the result of Jędrzej Stęszewski [05] due to several reasons such as the model of transistors, simulator type and the electronic properties of SiC semiconductors.

3.3 Influence of temperature on the transconductance g_m *(T)*

To investigate the evolution of the transconductance g_m of a MOS transistor as a function of temperature, we would exploit the transfer characteristic $I_D = f(V_{DS})$. The transconductance is determined by the following relation [04]:

$$g_m = \frac{\Delta I_{DS}}{\Delta V_{GS}} \quad (2)$$

Based on this relation the transconductance were identified as shown in the following figure:

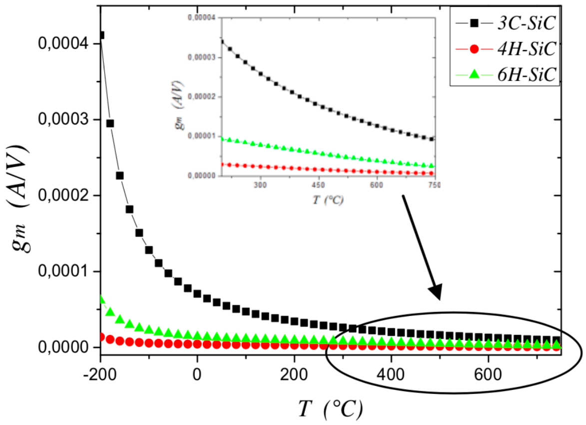

Fig. 4. Transconductance as function of temperature of the NMOS transistors.

The simulated transistors operate in saturation region ($V_{DS} > V_{dsat}$). Starting from the BSIM3v3 model drain relation in this region [04] and following a simplification, expression of transconductance can be written [11]:

$$g_m(T) = WC_{ox}v_{sat}(T) = \frac{1}{2}WC_{ox}E_{eff}\mu_{eff}(T) \quad (3)$$

The transconductance is an important electrical parameter that characterizes MOS transistor in order to study its performances [12]. The saturation velocity and carrier mobility decrease when temperature increase [03]. Then the transconductance g_m is directly proportional to the derivative of mobility with respect to gate voltage V_{GS} [13], and is proportional to saturation velocity as shown in Fig- 3. The maximum operating temperature of silicon carbide is very high [14]. In our work, we simulated our components in temperature range of -200 ° C to 750 ° C. For that, we found the variation in transconductance g_m as function of temperature as indicated in Fig- 4. The studied transistors have yielded satisfactory results in this range.

3.4. Frequency-response of MOSiC transistors

For the dynamic study, we have attacked our devices with low amplitude analog complex signal. We have adopted the high frequency equivalent circuit of Fig- 5.

The different transistors are in saturation mode, the transition frequency of a MOS transistor is related to the electrical elements values of the equivalent circuit diagram (Fig- 5).

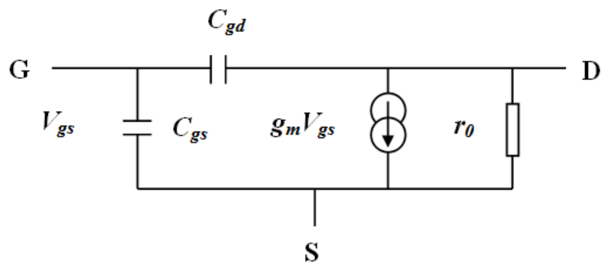

Fig. 5. Equivalent circuit small signal MOS transistor [15].

Transition frequency expression of MOS transistors is [16-17]:

$$f_T = \frac{g_m}{2\pi(C_{gs}+C_{gd})} \quad (4)$$

With g_m Transconductance in saturation mode.
C_{gs} and C_{gd} : Gate-Source and Gate- Drain capacity .
They are given by equations (5) and (6).

$$C_{gs} = \frac{2}{3}WLC_{ox} + WL_{ov}C_{ox} \quad (5)$$

$$C_{gd} = WL_{ov}C_{ox} \quad (6)$$

With $L_{ov} = \frac{C_{gdo}}{C_{ox}}$ where C_{gdo} is PSpice parameter of BSIM3v3 model.

The structure dimensions and oxide type used are the same for the three types of studied transistors. Then, the expression $2\pi(C_{gs} + C_{gd})$ depends only on transistor dimensions and oxide capacitor C_{ox}. Its value is the same for the three types of MOSiC transistor. Thus, the transition frequency is directly proportional to transconductance of transistors.

In Table- 3, we carry the frequencies determined together with a summary of different determined results.
From our results, we conclude that the 3C-SiC technology transistor is characterized by high operating frequency compared with other transistors (MO(4H-SiC) and MO(6H-SiC)).

Table- 2 shows the comparison between our MOS transistors of the different SiC technologies.

Table 2. Results of the different parameters determined of MOSiC transistors.

Parameters	**MOS(3C-SiC)**	**MOS(4H-SiC)**	**MOS(6H-SiC)**
I_{Dsat}(µA)(to V_{GS}=1.2V)	74.946	4.7449	15.903
V_{th} (V)	0.38	1	0.71
Operating temperature (°C)	≥ 700	≥ 550	≥ 600
f_T (GHz)	42.24	9.8049	15.099

In our work, we have shown that the MOS transistors in silicon carbide submicron technology work well in low voltage, low power, high frequency and a wide temperature range.

4. Conclusion

Our MOSiC transistors (3C, 4H and 6H) are calculated for 130nm technology, then simulated by OrCAD 16.5 software (PSpice) BSIM3v3. We have shown that the energy gap and carrier concentration are responsible for the evolution of different electronic characteristics of our transistors. Our simulation shows that our MOSiC transistors operate correctly in a temperature range of - 200 ° C to 750 ° C for 1.2V supply voltage. The transition frequencies are relatively high. They can reach about forty GHz. SiC transistors are designed to operate in high voltage and high power. We have demonstrated that they can be submicron and they operate at low voltage, low power and high temperatures

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