CHARACTERIZATION OF SIC HF-POWER MESFETS UP TO 250˚C

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ABSTRACT

4H-SiC metal-semiconductor field effect transistors (MESFETs) [1] were characterized at 25, 100, 150, 200, and 250 ˚C and two-dimensional electro-thermal simulations [2] were performed to examine the effects of elevated device operating temperature and self-heating on DC and RF performance of the MESFETs. The gate and drain characteristics (Id-Vg & Id-Vd) were measured at room and elevated temperatures. The pinch-off voltage increased with temperature and drain voltage. The shift of the pinch-off voltage was more prominent at low temperatures (2 V from 25 to 100 ˚C) than at high temperatures (negligible shift above 150 V). No short channel effects could be seen in drain characteristics due to the self-heating effects. The measured knee voltage and saturation current differed to some extent from the simulated values, which could be caused by the surface and the substrate traps that were not included in the simulations due to the difficulty to describe the temperature dependence of the trap behaviours. The current gain and power gain were measured as a function of frequency. Decrease of f_T and f_{max} with increase of temperature was observed for both measurements and simulations. Higher f_T and f_{max} were obtained from simulations than from the measurements. Traps and parasitics are believed to be the cause for the differences. A strong influence of contact resistance was seen on f_T and f_{max} in the HF simulations.

INTRODUCTION

4H-SiC MESFETs show great promise for high-power microwave applications such as transmitters for wireless communications system, radar, etc., thanks to the superior material properties and the relatively mature material growth and device fabrication technology [3, 4]. The devices are particularly attractive for high temperature applications since less cooling is required for the devices due to the high thermal conductivity of the material and the low intrinsic carrier concentration allows high junction temperatures. With the first commercial SiC RF power MESFET by CREE [5], an abundance of experimental [6, 7, 8] and simulation work [1, 8, 9] has been conducted to investigate the potential of the RF power performance of 4H-SiC MESFETs. In this report the DC and HF performance of 4H-SiC RF Power MESFETs at elevated temperatures up to 250 ˚C were investigated through simulations and measurements.

EXPERIMENTAL AND SIMULATIONS

The measurements were carried out on a probe station equipped with a hot chuck. A HP4156 semiconductor parameter analyzer and a HP8510A network analyzer were used for current-voltage measurements and HF S-parameter measurements respectively. The measurements were performed up to 250 ˚C and 26.5 GHz.

Fully coupled electro-thermal simulations with temperature dependent electrical properties and thermal conductivity were performed using the ISE-TCAD software suite [2]. The drain and gate characteristics were simulated at room and elevated temperatures under two conditions: with and without self-heating. Small signal simulations were performed at elevated temperatures up to 250 ˚C. Current gain and power gain were calculated from the S-parameters. The cut off frequency f_T and the maximum frequency of oscillation f_{max} were extracted at different temperatures.

RESULTS AND DISCUSSION

The schematic structure of the MESFETs is shown in Fig. 1. It consists of a semi-insulating substrate, a p-type buffer layer, an n-type channel layer and an n^+ contact layer. The current flow from the drain to the source is controlled by applying a negative voltage at the gate, which depletes the n-channel.

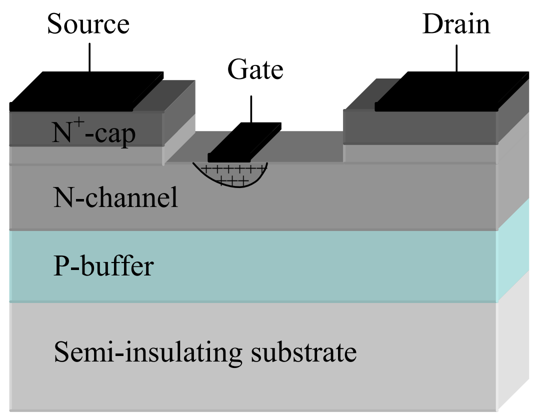

Fig. 1 Perspective of SiC MESFET structure.

The measured gate characteristics (I_d-V_g) at 25 ˚C and 250 ˚C are shown in Fig. 2. The threshold voltage (absolute value) increased with temperature and drain voltage. The shift of the threshold voltage was more prominent at low temperatures (2 V from 25 to 100 ˚C) than at high temperatures (negligible shift above 150 ˚C). A reasonable explanation of the dependence of the threshold voltage on temperature is the deep level traps in the substrate/buffer, which induce extra charges at the channel-buffer interface acting as a backside gate. As the temperature increases the de-trapping starts to occur and the depletion from the backside to the channel becomes smaller, which means an increase of the threshold voltage. Fig. 3 shows the drain characteristics (I_d-V_d) from measurements and simulations for a device operating at 250 °C. Good saturation and linearity were seen for devices operating up to 250 °C. No short channel effects could be observed due to the self-heating effects, which result in smaller drain current (compared with the drain current without self-heating). The higher the drain voltage, the more heat dissipated, the higher the lattice temperature, and the larger reduction on mobility, saturation velocity, the drain current, and

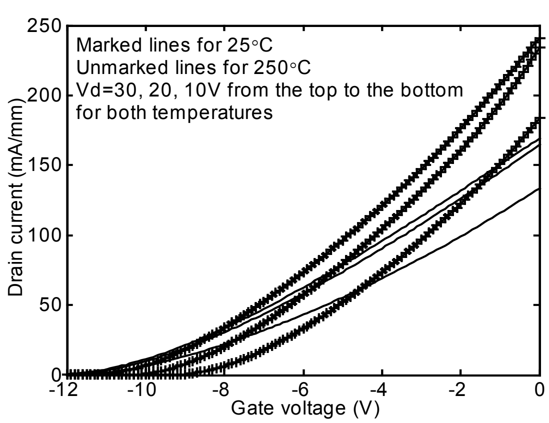

Fig. 2 Measured gate characteristics at 25 °C and 250 °C.

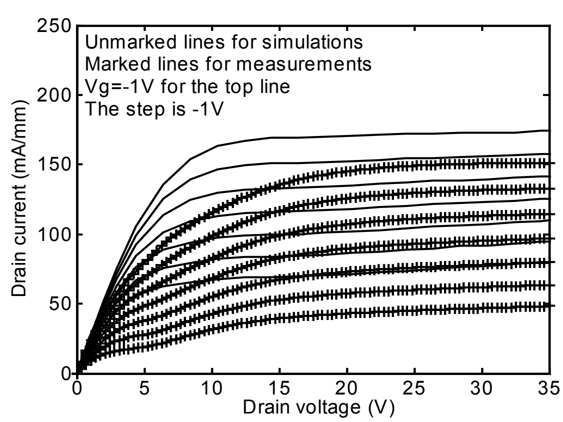

Fig. 3 Measured and simulated drain characteristics at 250 °C.

the maximum power density. The measured knee voltages are larger than the simulated knee voltages and the saturation currents are smaller compared to the simulated values. The differences could be caused by the surface and the substrate traps, which were not included in the simulations due to the difficulty to describe the temperature dependence of the trap behaviour.

For high frequency measurements the current gain and power gain were measured as a function of frequency. Fig. 4 and Fig. 5 demonstrate the measured and simulated current gain and power gains. The measurements show a decrease of the f_T and f_{max} with a temperature increase from 25 °C to 250 °C. Higher f_T and f_{max} were obtained from simulations. Traps and parasitics are believed to be the main causes for the differences between the measurements and the simulations. A strong influence of contact resistance, R_c, was seen on f_T and f_{max} in the HF simulations. The measured and simulated f_T and f_{max} at 25 and 250 °C are shown in Table 1.

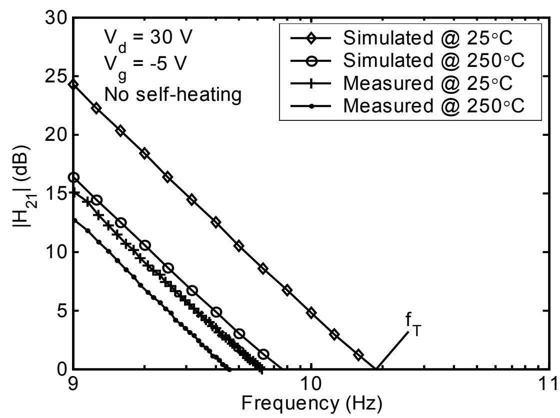

Fig. 4 Measured and simulated current gains at 25 °C and 250 °C.

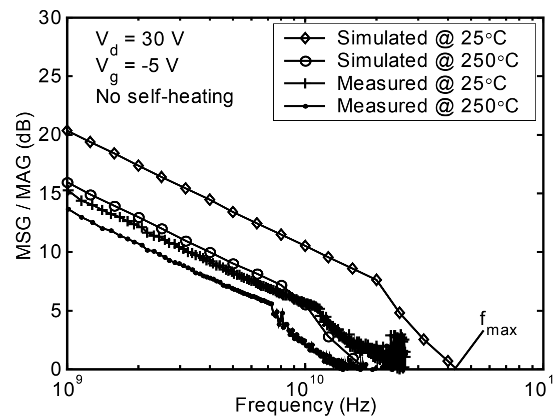

Fig. 5 Measured and simulated power gains at 25 °C and 250 °C.

Table 1 Measured and simulated cut-off frequency and maximum frequency of oscillation

T(°C)	***f_T simulated (GHz) $R_c = 0$***	***f_T simulated (GHz) $R_c = 10^{-4}\ \Omega\cdot cm^2$***	***f_T measured (GHz)***	***f_{max} simulated (GHz) $R_c = 0$***	***f_{max} simulated (GHz) $R_c = 10^{-4}\ \Omega\cdot cm^2$***	***f_{max} measured (GHz)***
25	34	18.5	6.2	>100	43.0	24
250	13	7.1	4.4	39	16	14

SUMMARY

4H-SiC Power MESFETs with a gate length of 0.5 um were characterized up to 250 °C through both measurements and simulations. The influence of the elevated operating temperature and the self-heating on threshold voltage, saturation current, maximum power density, current gain, power gain, f_T, and f_{max} were investigated. Although the DC and HF performance of the device degrades to some extent with increased temperature, the transistors still show attractive features at high temperatures up to 250 °C.

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