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Experimental Studies of Hot Electron Effects in GaAs MESFETs

Manfred Berroth, Michael Shur* and William Haydl
Fraunhofer-Institut für Angewandte Festkörperphysik
Eckerstrasse 4, 7800 Freiburg, West-Germany

We propose a new experimental technique of measuring the effective electron temperature in the channel of GaAs MESFETs. This technique utilizes the exponential dependance of the gate current in GaAs MESFETs on electron temperature in the channel. Using this new technique we measured the electron temperature as a function of the gate and drain bias in depletion mode ion-implanted GaAs MESFETs. These results indicate, that the random component of the electron motion is considerably reduced in constricted channels in field effect transistors.

1. Introduction

Hot-electron effects play an important role in determining the characteristics of short channel GaAs MESFETs. The saturation of electron velocity in the MESFET channel, along with overshoot and ballistic effects, determines the current voltage characteristics. The effective electron temperature, which may be considered as a measure of random electronic motion, can be linked to the noise characteristics and to the gate current.

The electric field in the MESFET is strongly nonuniform, with the maximum electric field near the drain side of the gate. Hence, electron heating by the electric field in an MESFET channel should also be non-uniform, with a larger effective electron temperature near the drain. One of the consequences of this hot-electron region near the drain is a large increase in the gate saturation current density, j_{gdo}, which depends exponentially on the electron temperature T_d at the drain side of the channel. Our technique of measuring the electron temperature is based on the exponential dependance of the gate current on electron temperature. We will show that there is a substantial difference between measured gate current and SPICE simulation results, using a DC equivalent circuit as shown in Fig. 1. We further show that the increase of gate current can be explained by an increasing electron temperature for both negative and positive gate bias.

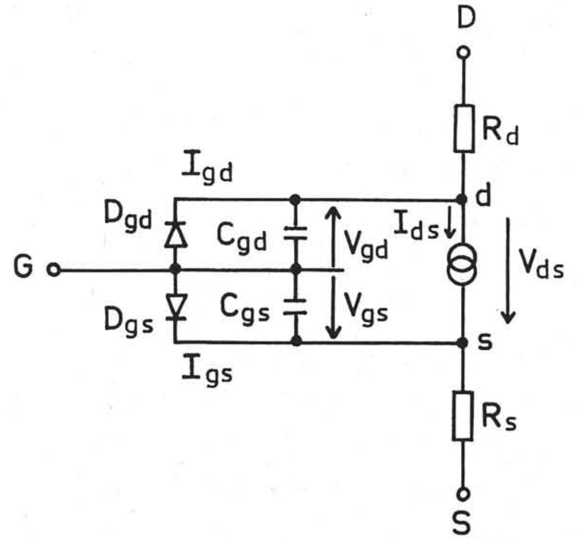

Fig. 1 Equivalent circuit of GaAs FET.

* Department of Electronical Engineering
Uni. of Minnesota, Minneapolis, MN 55455, USA

2. Basic Equations

To determine the electron temperature in a MESFET, it is necessary to have a simulation model, which describes the drain current characterisitc accurately as published by Berroth et al. [1], because the source series resistance reduces the gate to source voltage considerably. Our model is in an excellent agreement with measured and simulated data on both the I-V characteristics (see Fig. 2) and the gate current at 0V drain-to-source voltage (see Fig. 3). With reference to Fig. 1, the linear resistances R_S, R_D and R_G have to be determined experimentally to enable the calculation of the internal gate-to-source and gate-to-drain diode currents, which are given by

$$I_{gs} = I_{gs0}(\exp(\frac{qV_{gs}}{nkT_s})-1)+g_{min}V_{gs} \qquad (1)$$

$$I_{gd} = I_{gd0}(\exp(\frac{qV_{gd}}{nkT_d})-1)+g_{min}V_{gd} \qquad (2)$$

$$I_{gs0} = A^*T_s^2S_{seff}(\exp(\frac{q\phi}{kT_s})) \qquad (3)$$

$$I_{gd0} = A^*T_d^2S_{deff}(\exp(\frac{q\phi}{kT_d})) \qquad (4)$$

There A^* is the effective Richardson constant, k is the Boltzmann constant, Ø is the effective Schottky barrier height, g_{min} is a parsitic conductance parallel to each diode, n is the diode ideality factor, T_s and T_d are the electron temperature at source and drain, and S_{seff} and S_{deff} are the effective cross-sections of the gate-to-source and gate-to-drain diodes, respectively.

3. Measurements in the forward biased region

When applying a positive voltage to the gate, a decreasing gate current can be measured with increasing drain-to-source voltage. However, this decrease is much less pronounced that is expected by equations (1) and (2). Fig. 4 shows this measurement in comparison to a SPICE simulation ($T_s = T_d = 300$ K), which deviates by orders of magnitude at higher drain voltages. From the intersection of additional simulations (with increasing $T_d = T_s$) with the experimental data, the corresponding channel temperature as a function of drain voltage is obtained.

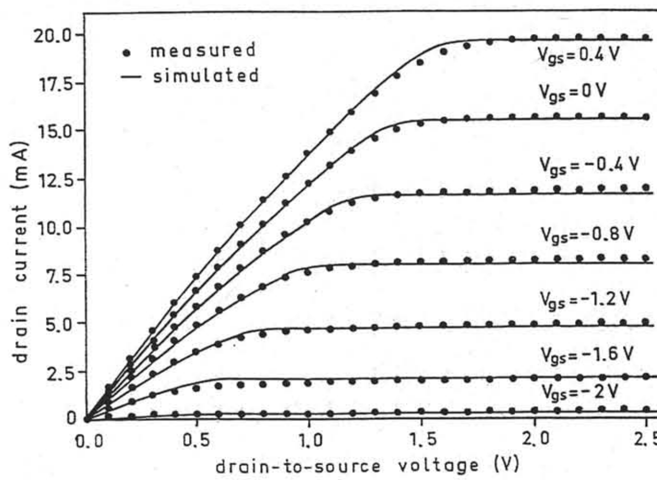

Fig. 2 Measured and calculated current-voltage characteristics of GaAs MESFET.

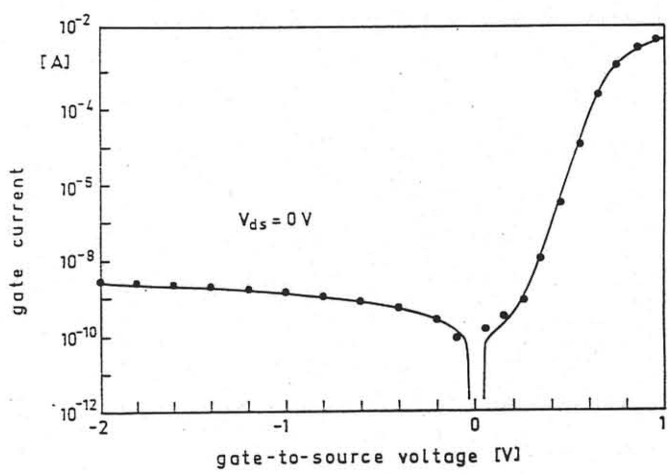

Fig. 3 Measured and simulated dependence of gate current on gate voltage.

The experimentally determined electron temperature with increasing drain-to-source voltage is shown in Fig. 6. The electron temperature in the MESFET channel increases very rapidly at low drain voltage and saturates at a temperature of about 395 K.

The measurement with the forward biased gate was done assuming identical temperatures at source and drain. This method is more sensitive for determining the electron temperature on the source side, while the reverse biased gate measurement is more sensitive on the drain side.

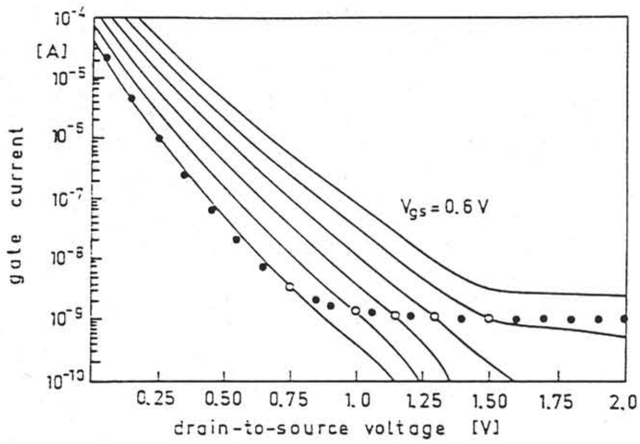

Fig. 4 Measured and simulated gate current of forward biased gate. Simulation are done with steps of 20 K starting at the lowest solid line with 300 K.

4. Measurements in the reverse biased region

When applying a negative voltage to the gate, the heating at the drain side can be observed at high drain-to-source voltages. Although the measured gate currents are small, still there can be a temperature correlated by the same method comparing measured data with simulation results with different temperatures (see Fig. 5).

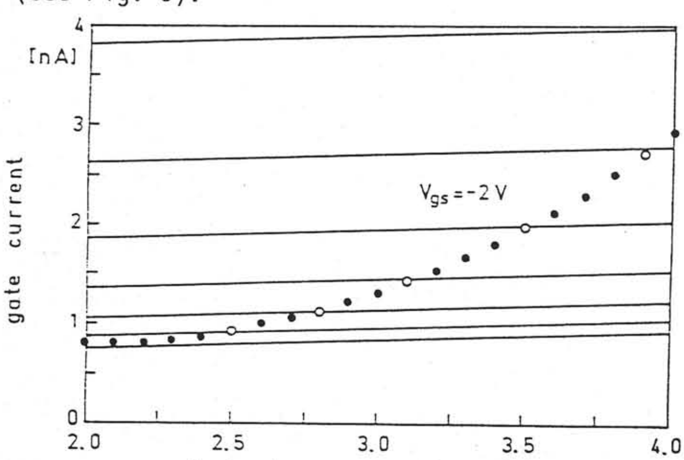

Fig. 5 Measured and simulated gate current at reversed biased gate. (T_d = 400 K...460 K).

Using these methods, the dependance of electron temperature from drain-to-source voltage and gate-to-source voltage can be extracted and, if necessary included into a circuit simulator like SPICE. With these modifications, the gate current can be simulated for all applied voltages.

5. Comparison with published MODFET results

Recently, experimental data of electron temperatures of MODFETs have been published [2] which are considerably lower than our experimental results (see Fig. 6). This may explain a superior noise performance of GaAs/AlGaAs Heterostructure FETs. The reduced noise in the MODFET can be explained by a less pronounced heating in narrow channels. This result suggests a new approach for designing low noise GaAs MESFETs.

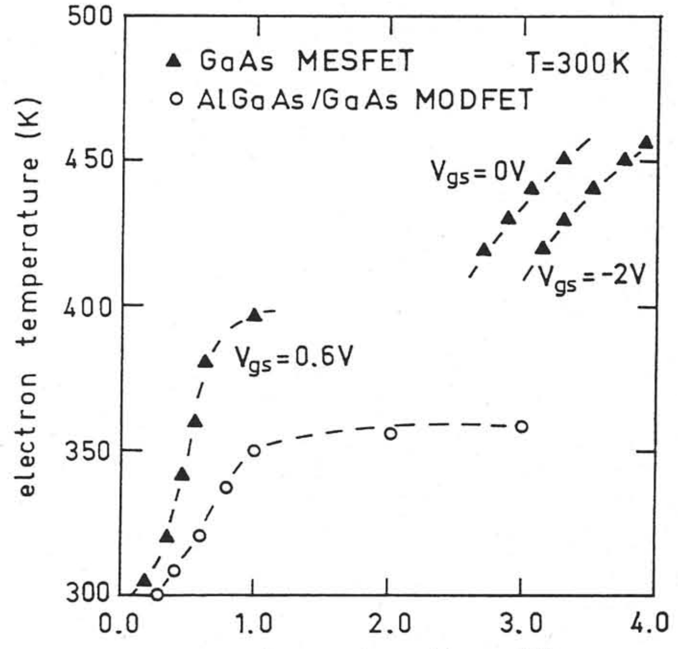

Fig. 6 Measured electron temperature for GaAs MESFETs and GaAs/AlGaAs Heterostructure FETs.

6. Conclusion

We have shown a new experimental techniques of measuring the effective electron temperature in the channel of GaAs MESFETs. The measured electron temperature of our ion implanted MESFETs were higher than those published for MODFETs. This new technique might be a useful tool for designing low noise GaAs transistors. It also improves the modelling of the gate current by circuit simulators like SPICE.

7. Acknowledgement
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1) M. Berroth, M. Shur, and W. Haydl. Hot Electron Model for GaAs Metal Semiconductor Field Effect Transistors, Proceedings of 1988 Electronic Devices and Material Symposium, August (1988).

2) C. Chen, S. Baier, D. Arch, and M. Shur. A New and Simple Model for GaAs Heterojunction FET Characterisitcs, IEEE Trans. Electron Devices, ED-35, No. 5, pp. 570-577, May (1988).