CURRENT TRANSPORT IN DOUBLE HETEROJUNCTION HEMTS

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Abstract

Simulations and measurements of a submicron pseudomorphic high electron mobility transistor (HEMT) are presented. For the simulations the generic device simulator MINIMOS-NT [1] is used which is capable of dealing with complex device geometries as well as with several physical models. The simulator allows a simulation of the extrinsic behavior of a HEMT. Two different methods of contacting the channel in the simulation are compared, source and drain metal directly contacting the channel versus contact metal only on top of the cap layer. It is shown that one has to include all heterojunctions in the current path to obtain a proper simulation of the transconductance of a HEMT. Moreover, it is shown that hydrodynamic simulation in the channel is also necessary.

1. Introduction

Double heterojunction HEMTs are becoming widely used for lownoise and high power microwave applications. Simulation can be a powerful tool for further improvements in device design. One of the most important DC parameters of a transistor for circuit design is the maximum transconductance $g_{m\ max}$. In this work, the DC characteristics of a pseudomorphic double-heterojunction AlGaAs/InGaAs HEMT with a gate length of 240 nm are investigated. For simulation of the transconductance, the modeling of the contacts turns out to be a crucial issue because it determines the current path from source to drain. Additionally the current densities will be influenced by short channel effects, namely real space transfer (RST). To account for RST, hydrodynamic simulation has to be performed in the channel of the HEMT.

2. Simulation

The electrical behavior of a HEMT is mainly determined by the epitaxially grown structure. To account for almost abrupt changing materials several distinct regions of semiconductor alloys can be combined in the simulation, each having their own material and electrical properties. Moreover the simulator MINIMOS-NT offers the option to apply different transport models in different regions, like a hydrodynamic model in the channel and pure drift-diffusion in the remaining regions, resulting in a mixed model simulation. This is a very efficient way of reducing computation time and improving convergence which is known to be weak for hydrodynamic simulations. The different regions are linked together by interface models. A thermionic field emission model is used to describe the transport across semiconductor interfaces. Particularly, tunneling is included to enable electrons to cross the interface between the channel and the barrier layers.

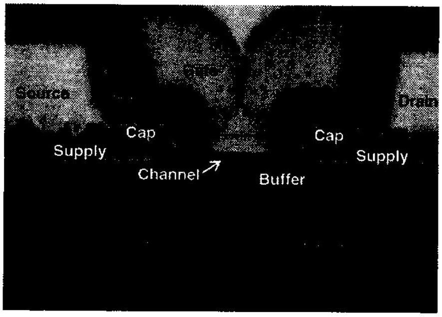

Fig. 1: SEM profile of the simulated HEMT.

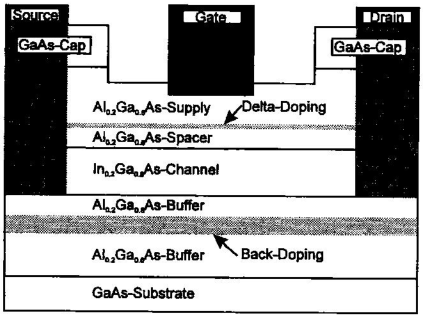

Fig. 2: Structure of the simulated HEMT. The shaded areas indicate directly contacted channel

For simplicity, most authors assume the drain and source metals to contact the channel directly [2,3]. A representative Scanning Electron Microscopy (SEM) profile, shown in Fig. 1, does not indicate that this is really the case. Therefore, one can assume that the heterostructures are not destroyed by alloying the contact metal. This assumption becomes more evident from mobility measurements [4]. The structure of the simulated device is shown in Fig. 2. The dark shaded areas indicate the drain and source metals which are assumed to contact the channel directly for some of the simulations.

3. Results

Simulations of the characteristics of a delta doped HEMT with a gate length of 240 nm are compared with the measured data. Fig. 3 shows the measured transfer characteristics of the device along with the simulation results, one with directly contacted channel, the other with ohmic contacts only on top of the cap layer, both with mixed model simulation. As depicted in the figure, the simulation with contacts just on top of the cap layer and the measurement compare quite well. Especially for positive gate voltages, the simulation which assumes contacts direct to the channel deviates strongly from the measurement. In this case Fig. 4 shows a significant overestimation of g_m for high gate voltages. Neither the location of the maximum of

g_m nor its magnitude is described very well. This behavior can be attributed to an improper current density distribution as a consequence of the direct contact to the channel.

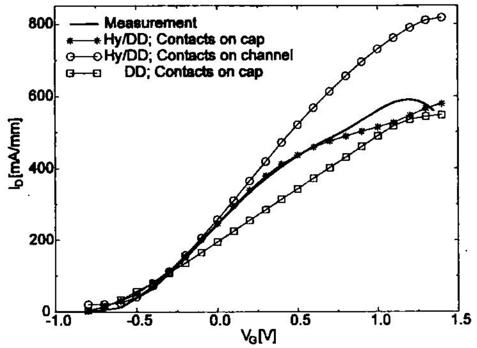

Fig. 3: Transfer curves of the HEMT.

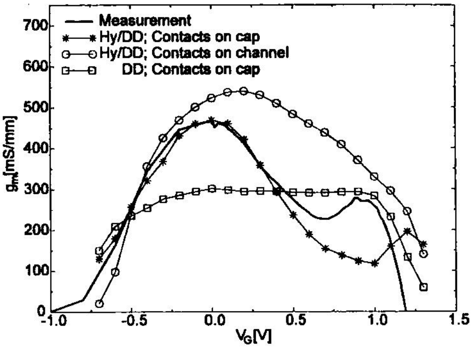

Fig. 4: Transconductance of the HEMT

In this case, a significant amount of current is flowing directly from the InGaAs channel into the drain contact, as shown in Fig. 5. Two main current paths can be observed, the first from the channel directly to the drain contact, the second path from the channel over the barrier and through the cap to the drain. Since the current path of the simulation with directly contacted channel is partly wrong, the current for high V_G is still governed by the gate voltage in an almost linear way resulting in only a weak reduction of g_m for V_G larger than 0.3V. This is different in the simulation of the device with contacts on top of the cap layer.

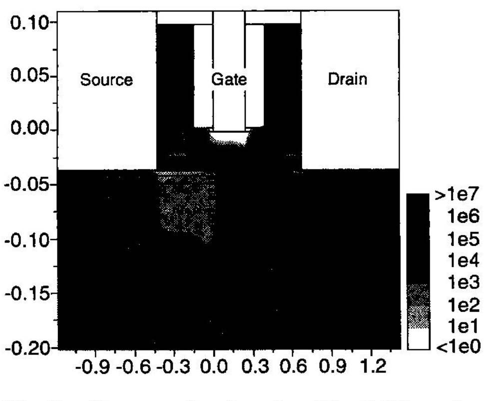

Fig. 5: Current density for V_G=0.5V and V_D=2.0V with contacts directly on the channel.

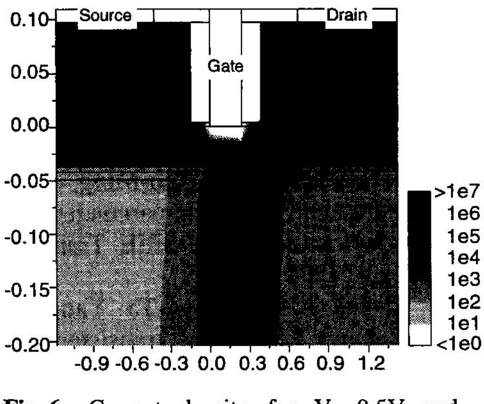

Fig. 6: Current density for V_G=0.5V and V_D=2.0V with contacts only on the cap.

In both simulations a hydrodynamic model is applied on the channel to calculate the carrier temperature. In the drift-diffusion model carrier heating is implicitly taken into account by a local field dependent mobility model [5]. The carrier temperature at the interfaces on both sides of the channel is assumed to be the temperature of the channel side (≥ 300 K). For gate voltages higher than 0.3V, the electrons heat up and start to surmount the energy barrier between the channel and the barrier layers (RST). An increasing amount of current is conducted in the AlGaAs layers where the mobility of the electrons is rather low. This results in a strong reduction of g_m.

A similar problem occurs when pure drift-diffusion is employed for simulation. Again RST is underestimated, in this case for the reason of an underestimated carrier temperature in the channel which is kept constant at 300 K. The transfer characteristics and the g_m for a plain drift-diffusion simulation are also shown in Fig. 3 and Fig. 4, respectively. The threshold voltage is similar to the other simulations. The current density stays lower because no velocity overshoot is considered. The g_m stays almost constant over a wide range of V_G for the reason of missing RST.

4. Conclusions

A quarter micron delta doped HEMT is simulated with the generic device simulator MINIMOS-NT. Two different possibilities of modeling the contact of a HEMT are compared. Mixed model as well as plain drift-diffusion simulations were performed. It is shown that for a proper simulation of the transfer characteristics it is necessary to include all heterojunctions in the current path, i. e., only to contact the cap layer by the source and drain metals, as well as hydrodynamic simulation in the channel. This becomes increasingly important when device geometry such as channel length is shrinked further.

References

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