Simulation of Ultra Short Channel InAlAs/InGaAs/InP High Electron Mobility Transistors by a Coupled Solution of the Schrödinger Equation with a Hydrodynamic Transport Model

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The simulation and measurement of ultra short channel high electron mobility transistors (HEMT), based on InAlAs/InGaAs/InP, are presented. These structures are experimentally investigated at the DaimlerChrysler AG. For the simulation the device simulator SIMBA is used, where several physical models (e.g. drift diffusion (DD) model, hydrodynamic (HD) transport model and a coupled solution of the Schrödinger equation [1] with a HD transport model) are included.

The device structure used for the simulation is represented in Fig. 1 together with the doping densities. Fig. 2 and Fig. 3 show the calculated output and transfer characteristics, respectively. Additionally the results of a HD transport model and measurement data are inserted. Essential physical effects (e.g. short-channel and overshoot effects), which determine the behavior of the HEMT structure, can be identified in the corresponding device characteristics. The difference between the simulation models consists in the computation of the electron density at the hetero interface, which was exactly calculated by a solution of the Schrödinger equation with a HD transport model. Fig. 4 shows the power gain as a function of frequency (MSG/MAG). The transit frequency f_T = 132 GHz and the maximum frequency of oscillation f_{max} = 176 GHz are obtained by a dynamic simulation at the working point V_{DS} = 1.1 V and V_{GS} = -0.3 V. In this point the device possesses the maximum transconductance with g_m = 760 mS/mm.

The capability of device simulation contains the possibility to investigate scaling effects. The performance, especially the output and transfer characteristic, of InAlAs-based HEMT has been evaluated as a function of gate length (l_G) in the range from l_G = 7 nm to l_G = 120 nm and for a corresponding scale of vertical dimensions. In Fig. 5 the output characteristic are illustrated for different gate lengths at V_{GS} = 0.

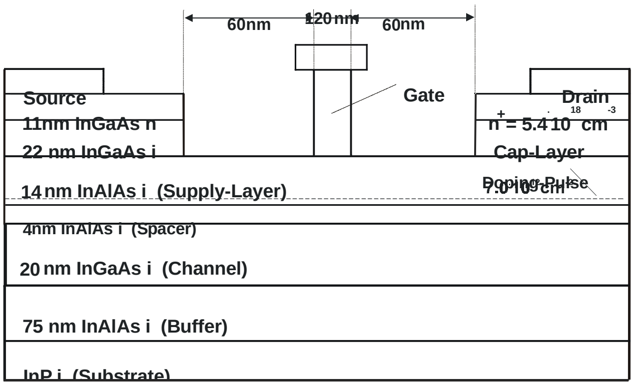

Fig. 1 Structure of the InAlAs/InGaAs/InP-HEMT

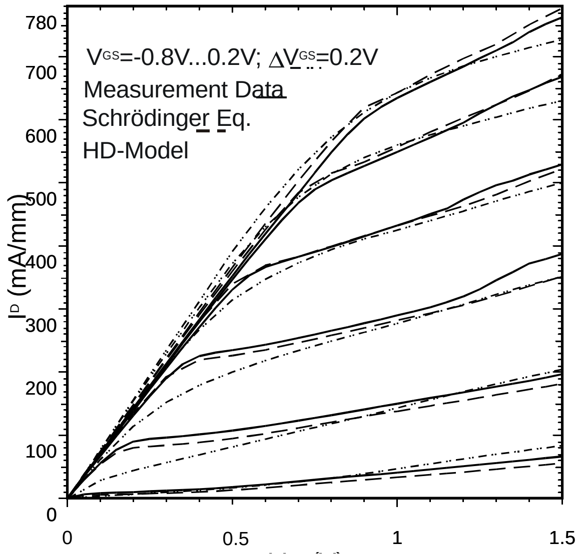

Fig. 2 Output characteristic for different simulations models

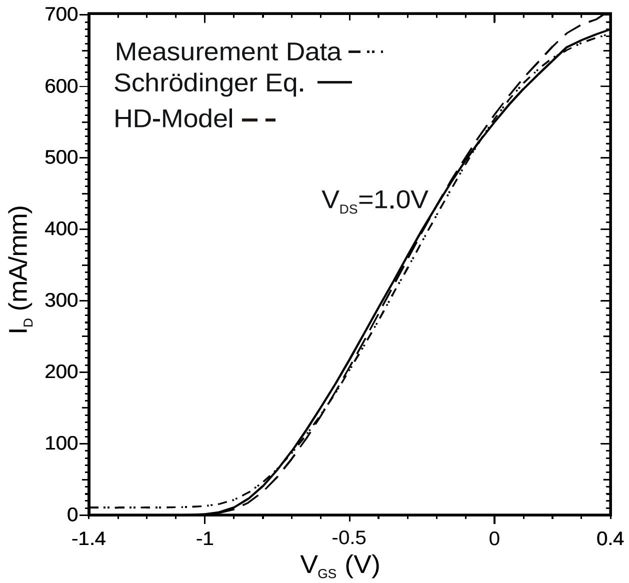

Fig. 3 **Transfer characteristic for different simulations models**

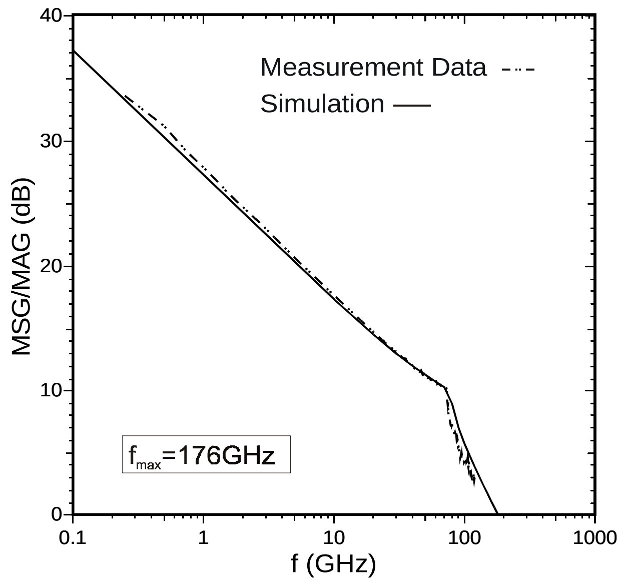

Fig. 4 **Calculated and experimental results of MSG/MAG (V_{DS} = 1.1 V; V_{GS} = -0.3 V)**

The behavior at extremely short gate lengths shows essential scaling effects like short-channel and overshoot behavior. As a result of dynamic simulation at the working point V_{DS} = 1.1 V, V_{GS} = -0.3 V for a 60 nm gate length f_{max} = 650 GHz was obtained. With the 30 nm gate length device f_{max} = 710 GHz can be achieved. The gate to channel aspect ratio, the threshold voltage and the maximum transconductance, for the gate lengths in the range from l_G = 7 nm to l_G = 120 nm, are summarized in Table 1.

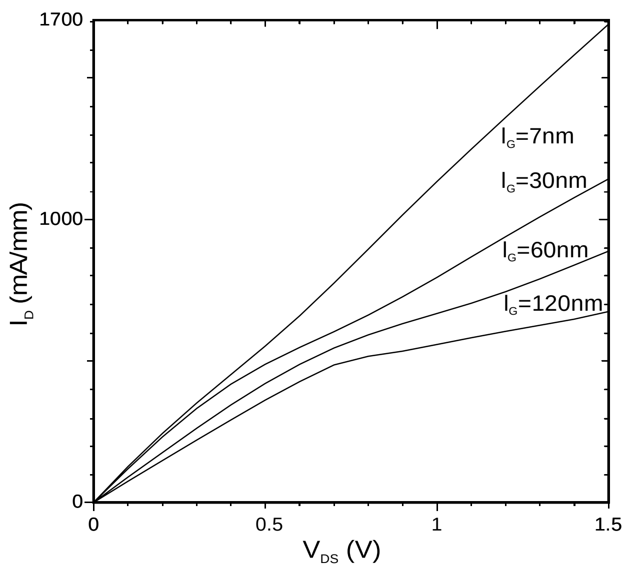

Fig. 5 **Output characteristic for different gate lengths at V_{GS} = 0**

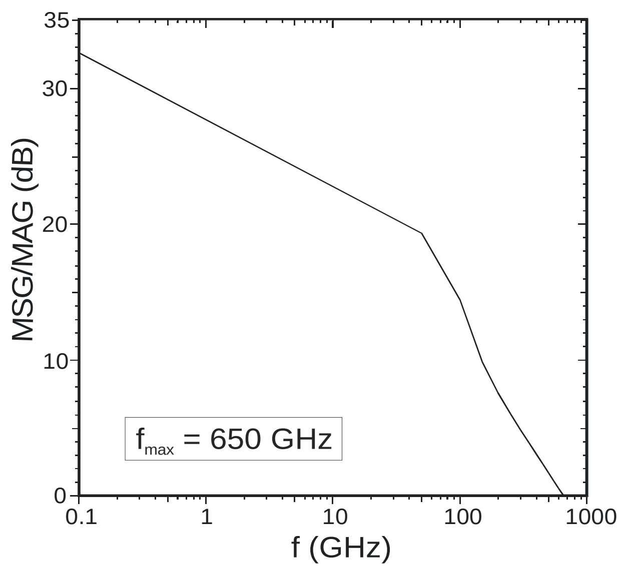

Fig. 6 **MSG/MAG for the HEMT-Structure with l_G = 60 nm (V_{DS} = 1.1 V; V_{GS} = -0.3 V)**

Table 1 **Parameters of the ultra short channel InAlAs/InGaAs/InP-HEMTs**

Gate length l_G (nm)	**7**	**15**	**30**	**60**	**120**
Gate to channel aspect ratio	2.33	3.0	3.0	4.0	6.66
Threshold voltage V_{th} (V)	-0.85	-0.75	-0.9	-1.1	-0.9
Maximum transconductance g_m (mS/mm)	2600	2225	1875	750	738

[1] C. Pigorsch, W. Klix, R. Stenzel. Microelectronic Engineering, **43-44** (1998), pp. 325-333