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A Short Channel HEMT Model for Circuit Simulation Based on Physical Structure

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Based on the device structure, we have developed a new accurate short-channel HEMT model for circuit simulation. In order to simulate short channel HEMT device characteristics in circuit analysis, we have included the velocity overshoot effect, and calculated accurate equivalent circuit components directly from device structure and dimensions with a minimum fitting parameters. Using this method, we can estimate the device characteristics directly from device structure. We have calculated the I-V characteristics of HEMT and compared the calculated results with the experimental results for 0.3 micron gate-length GaAs/AlGaAs HEMTs. And using SPICE, we have also calculated microwave characteristics, such as S-parameters for design purposes.

1 Introduction

High Electron Mobility Transistor (HEMT) is used in such field of satellite broadcasting and high speed optical fiber communication systems as front-end amplifier devices, due to its low noise and high speed characteristics. And the higher frequency is used, the shorter gate length device is required. Therefore short channel phenomena such as electron velocity overshoot effect affects the device characteristics. To design such high frequency circuits, precise equivalent circuits and associated non-linear HEMT device models are required. And short channel effect have to be treated. In order to calculate the device characteristics for circuit analysis, such as I-V and microwave characteristics, we propose a method to obtain accurate equivalent circuit components directly from device structure and dimensions with a minimum fitting parameters including the velocity overshoot. In this paper, we will show the model in detail.

2 I-V Characteristics Calculation

As gate length of HEMT decreases, short channel effects and velocity overshoot phenomena [1] remarkably affect the I-V characteristics.

We employ a simple two-region model [2] which is divided into a linear and an overshoot velocity regions. And we assume that the velocity of electrons is proportional to the electrical field along channel in the linear region, and that in the overshoot region electrons ballistically pass through the channel under the gate near the drain region at the peak overshoot velocity [3].

We have calculated the I-V characteristics, the mutual conductance Gm and the drain conductance Gd, for a 0.3 μm HEMT [4] and compared them with the experiment results. Figure 1 shows the calculated I-V characteristics and conductances for GaAs/AlGaAs HEMT sample. Parameters used in the calculation are shown in Table 1. We used the device dimensions and physical constants with no fitting, except the overshoot velocity v_p and the saturation electric field E_p, which we estimated by Monte-Carlo simulation [5]. And conventional model calculation results (dashed lines) are also shown in the figure. Proposed method results are in good agreement with the experimental results in a middle gate voltage range with no fitting except the threshold voltage as shown in the figure.

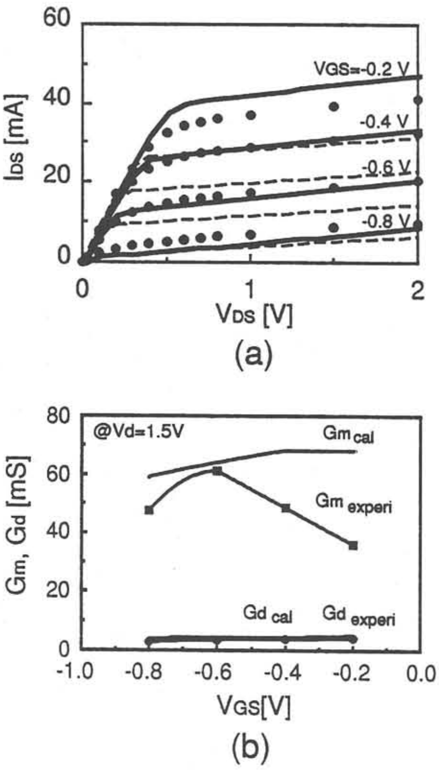

Figure 1: Calculated result of (a) I-V characteristics and (b) Gm and Gd, closed circle : experimental result and solid line : calculated result.

Since the electron sheet density saturates at high gate voltage (Fig. 2), the drain current also saturates. To adjust saturated current accurately in the high gate voltage range, we have introduced a few fitting functions based on physical model. We have chosen a 4-th order poly-

Table 1: Device Parameters

L_g	0.3 μm
W	200 μm
v_p	3.5×10^7 cm/s
μ_e	6800 $cm^2/V\cdot s$
E_p	9.0×10^3 V/cm
V_{th}	-0.86 V
ΔV_{th}	-0.064 V/V
R_D	5.0 Ω
R_S	5.0 Ω

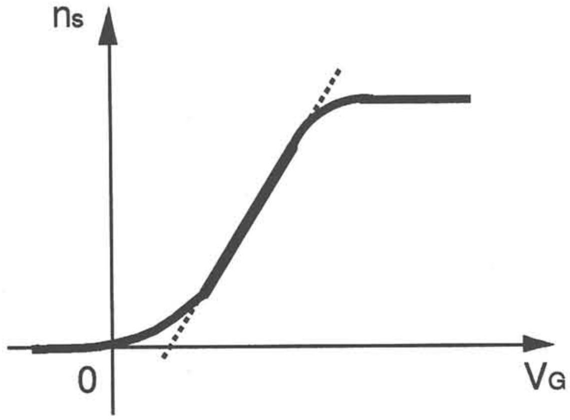

Figure 2: Electron sheet density vs. gate voltage.

nomial function $f(V_{GS})$ for drain current saturation consideration. For correction of slope in the saturation region another function $h(V_{GS}, V_{DS})$ is introduced. And the third function $k(V_{GS}, V_{DS})$ is for knee points of starting saturation because the lateral field between gate and source is strong enough to accelerate electrons in spite of low drain voltage when gate voltage is high. And to avoid discontinuity of derivative of I-V curve which causes serious convergence problems in circuit simulation, we introduce two functions to connect smoothly the boundary region between linear and saturation regions. Since this model is based on the two-region one, there is an evident discontinuity point in the first derivative of I-V curves. $g(V_{GS}, V_{DS})$ is for smoothing boundary region between linear and saturation regions [6]. And $k(V_{GS}, V_{DS})$ is combined with $g(V_{GS}, V_{DS})$ to adjust the transition region between linear and saturation. Then the drain current is expressed as following equation,

$$\mathrm{Id} = \mathrm{Id}_0 \cdot f \cdot h \cdot g \cdot k \qquad (1)$$

Figure 3 shows the calculated result. In the figure, closed dots denote the calculated results and solid lines are experimental results. The results are in good agreement at all of the gate and the drain voltage range. At this time, this result has been obtained by the accurate fitting, but most of coefficients of functions above can be estimated from device structure and dimensions.

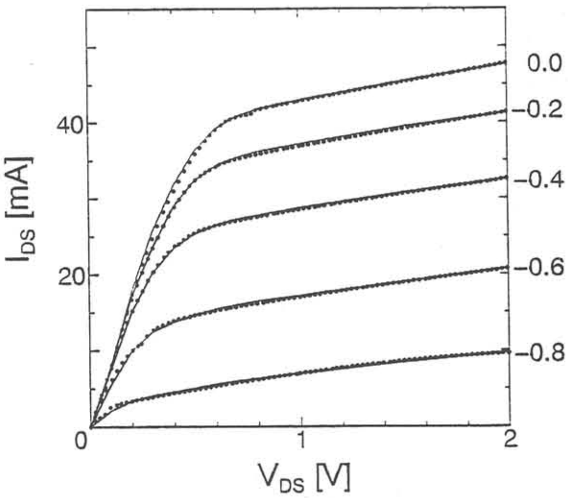

Figure 3: Calculation results.

3 S-parameter Calculation

At microwave frequency region, S-parameters are important factors to evaluate the device characteristics. We calculate S-parameters through the equivalent circuit. Figure 4 shows the flow chart of S-parameter calculation. First, we calculate the values of components of the lumped equivalent circuits as shown in Fig. 5, such as resistances and capacitances in the equivalent circuit directly from device geometry. Namely, we calculate capacitances between electrodes, such as C_g and C_d, source-gate and source-drain electrode capacitance respectively, using the Green's function method [7], and internal capacitances, C_{gs}andC_{gd}, i.e., gate-source and gate-drain capacitance respectively, from voltage derivatives of total channel charge calculated in the I-V characteristics calculation mentioned above. And other internal capacitance, drain-source capacitance C_{ds} is calculated as parallel plates. Resistances are obtained from device dimensions. Mutual conductance gm and drain conductance gd are obtained simultaneously when the I-V calculation is effected. Next, to obtain S-parameters, we calculate the Z matrix for the non-linear equivalent circuit obtained through the above calculation using SPICE, and convert the Z-matrix to the S-matrix. Then we can plot the S-parameters on the Smith chart.

Figure 6 shows the calculated result for the 0.3 micron gate HEMT. Two of the four S-parameters, S11 and S12 are in good agreement with the experimental result. But due to the calculation inaccuracy for some equivalent components especially C_{ds}, S22 and S21 are not in agreement with the experimental ones. Since we used the lumped equivalent circuit model, microwave-wave characteristics such as distributed parasitic element effects are not considered. It is possible to improve the accuracy of them by considering more precise equivalent circuits including the distributed parasitics.

4 Conclusion

We have proposed a method to calculate HEMT characteristics for circuit analysis based on physical structure. We have obtained an accurate model for I-V and

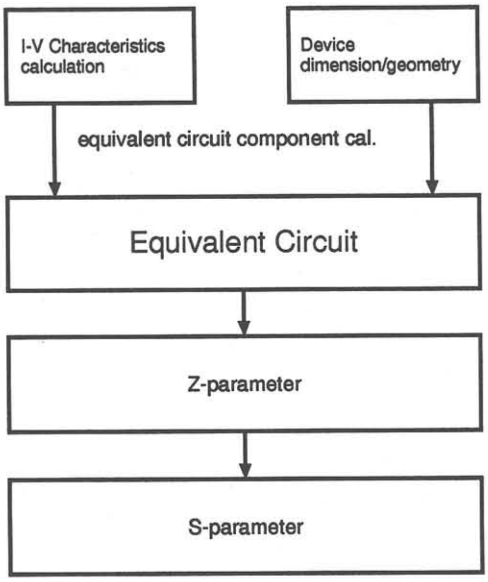

Figure 4: S-parameter calculation flow chart.

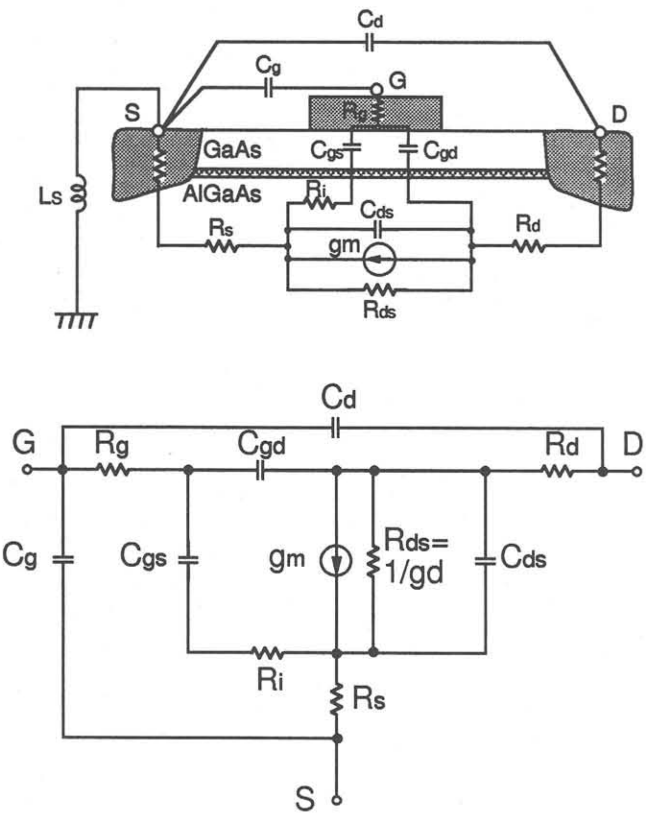

Figure 5: Equivalent circuit for S-parameter calculation.

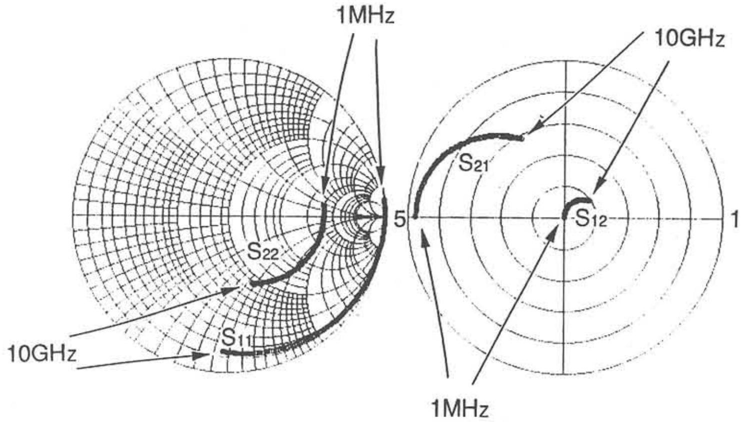

Figure 6: Calculated S-parameters, (a) S_{11} and S_{22}, (b) S_{12} and S_{21}.

microwave characteristics.

acknowledgment

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