A PHYSICS–BASED ELECTRO–THERMAL MODEL FOR MICROWAVE AND MILLIMETRE WAVE HEMTS.

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Abstract

An electro–thermal physical model is described for HEMT microwave and millimetre wave simulations which includes temperature effects due to self–heating within the device. Comparisons of the results from the model with measured data are made and it is found that good agreement is obtained without fitting of any of the parameters. The model is compatible with CAD requirements and is particularly suited to large–signal applications.

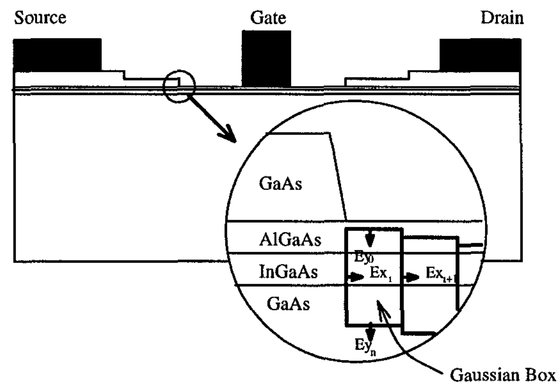

Figure 1: A Schematic of the HEMT.

Introduction

The advantage of physical models is their ability to predict the electrical output of a device from the device structure alone. This is a very powerful technique which is becoming more widespread in recent years with the increase in speed of computers and the development of quasi–two dimensional models (see for example Snowden and Pantoja [1, 2]). These developments mean that physical models can now usefully be incorporated with CAD packages.

Earlier physical models from Leeds dealt exclusively with MESFETs although more recently a physical HEMT model has been developed (Morton *et al.* [3]). The work has been extended so that the model now includes thermal effects. This is an important extension as the self–heating within devices leads to significant reduction in the power output. This paper describes an electro–thermal model based on a quasi–two dimensional description and demonstrates its applications to microwave CAD.

Model Description

The quasi–two–dimensional (Q2D) approach in this paper follows the methods originally developed by Snowden and Pantoja [1]. The model has been extended to apply to HEMTs by incor-

0-7803-4603-6/97/$5.00 (c) IEEE

porating an efficient charge control model. The Q2D model considers the channel as a succession of Gaussian boxes along the active channel (see Fig. 1). The charge within each Gaussian box is obtained from a look-up table. The details of the isothermal Q2D HEMT simulation are discussed by Morton *et al.* [3, 4].

In this paper, the work is extended to include thermal effects. Two–dimensional simulations of MESFETs have shown that the temperature distribution is far from uniform (Santos [5]). However, excellent agreement with electrical characteristics has been found for MESFETs using a uniform channel temperature approach [2, 6].

The channel temperature is obtained from the output power by the relation

$$T_{chan} = T_{amb} + I_{ds} V_{ds} R_{th}$$

where T_{chan} is the channel temperature, T_{amb} is the ambient temperature and R_{th} is the thermal resistance of the material in the device. This gives the amount of self–heating within the device; the major effect this has on the electrical characteristics is via the electron mobility, μ, which is strongly dependent on temperature. The relation used in this paper follows the work of Blakemore [7] who derived the expression

$$\mu(T_{chan}) = \mu(T_{amb}) \left(\frac{T_{amb}}{T_{chan}} \right)^n .$$

Experimental results show that $n \approx 2.3$ and this value has been used in the work described in this paper.

The solution of this new model is similar to the original Q2D HEMT simulator which is a current–driven model that is solved along the channel from source to drain. At each step, the field is calculated in a self–consistent way with charge within the Gaussian box. In this way, v_{ds} is obtained for a given current i_s. However in this case, v_{ds} is also dependent on the temperature which is itself dependent on v_{ds} and i_{ds}. This dependency is dealt with by the additional iteration of the temperature until a convergent solution is formed with the correct output power. This is typically achieved in three iterations.

The algorithm which predicts the next point along the I-V characteristics is complicated because these curves are no longer monotonic so i_{ds} may decrease as well as increase with increasing v_{ds}. While this does decrease the speed of the simulator, it is still possible to get a full suite of I-V curves in 2-3 mins on an HP710/80 workstation.

S-parameters are calculated at a bias point which is computed with thermal effects taken into account although it is assumed that the small signal RF disturbances are sufficiently small that additional changes in temperature are negligible. Typically, an S-parameter calculation takes 6-8 seconds per bias point.

The model is also suited to the calculation of large–signal RF characteristics. These can either be done directly in the time domain or via the HP Root Model.

Results

The device simulated was a GMMT (Caswell) 6×60 micron HEMT. The thermal resistance was taken to be 90 °C/W. Fig. 2 shows the DC I-V characteristics for the simulation and comparison with measured data. The S-parameters for the Caswell HEMT at a bias of $V_g = 0.0, V_{ds} = 3.0$ are shown in Fig. 3. The measured data (solid lines) is compared against the simulated results (dashed lines) and this gives good agreement. It should be stressed that these results are obtained using the nominal physical structure of the device without any fitting of parameters.

The surface temperature distribution for an eight finger power HP HEMT with a gate width of 1.92 mm is shown in Fig. 4 and was ob-

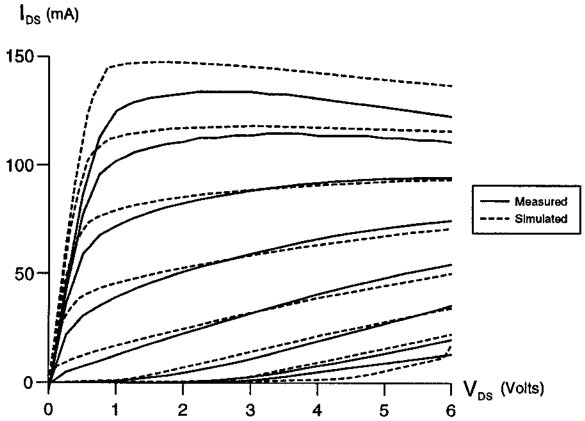

Figure 2: The I-V curves for the GMMT HEMT.

tained using a three–dimensional thermal simulator Heatwave [8]. A multi–cell thermal equivalent circuit model was extracted from this data using the technique described in [8] (yielding a net thermal resistance of 16 °C/W for this power device). Again a simulation of the I-V characteristics using this value of thermal resistance gives excellent agreement with measured data.

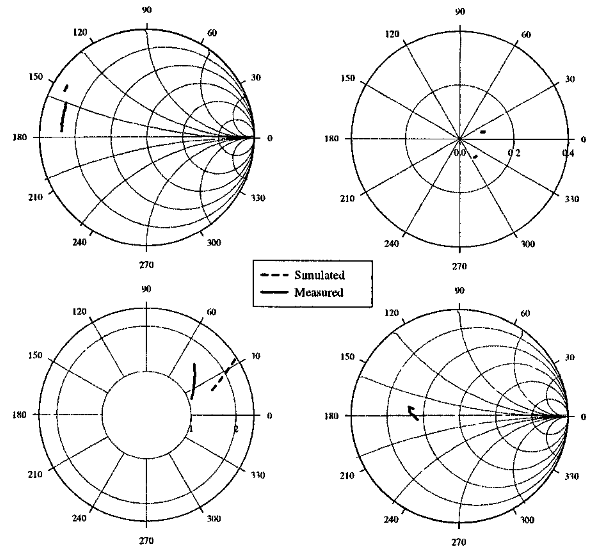

Figure 3: The S-parameters for the GMMT HEMT at a bias of $V_g = 0.0, V_{ds} = 3.0$.

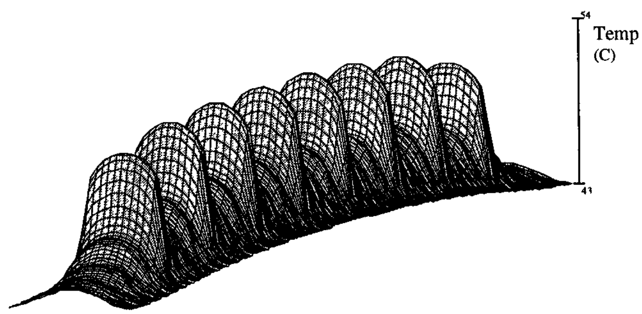

Figure 4: A surface temperature contour plot for an eight finger power HEMT.

Conclusions

The results presented in this paper show that it is possible to include thermal effects in a HEMT simulator which is still sufficiently fast that it can be used within a CAD package. The results show good agreement with measured data and the methods described here allow considerable insight into the HEMT behaviour.

Acknowledgements

The authors acknowledge funding from HP–EEsof, Santa Rosa, CA. We are also grateful to A. Plews for providing the measured data for the Caswell HEMT and C.G. Morton for the HP HEMT.

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