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Ultra - Linear Pseudomorphic HEMTs for Wireless Communications : A Simulation Study

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In this paper, we apply numerical device simulation in the design of pseudomorphic HEMTs with improved linearity and reduced intermodulation products aimed at wireless communications applications. We show that in channel doped GaAs pHEMTs the introduction of a p-doped buffer layer significantly improves the device linearity leading to a 10dB suppression of 3rd order distortion over a wide bias range with similar gain when compared with a more standard δ-doped GaAs pHEMT device.

1. Introduction

In recent years, there has been rapid and sustained growth in the telecoms industry, especially in the field of mobile communications, as well as the emergence of large potential markets in the areas of wireless local area networks. The growth of digital services such as fax, video conferencing and internet access has led to an ever increasing pressure to maximise the utilisation of available bandwidth, which has led to the use of highly efficient modulation schemes together with tight channel spacings. Intermodulation distortion in key parts of the radio link can lead to serious degradation of channel quality resulting in data loss. A range of design techniques exist for minimising intermodulation distortion in components such as amplifiers and mixers, but performance is ultimately determined by the distortion introduced by the transistors around which such circuits are designed. In this paper, we use well calibrates numerical simulations in the design of pseudomorphic HEMTs with improved linearity and reduced intermodulation products aimed at wireless communications applications.

2. Calibration

The starting point for the simulation based design is a standard 0.12 μm gate length T-gate pHEMT fabricated at the Nanoelectronics Research Centre of Glasgow University [1]. The vertical layer structure of the device is shown in Fig. 1. The free carriers in the 2DEG are supplied by a δ-doping layer separated by a 2.5 nm spacer from the pseudomorphic InGaAs channel.

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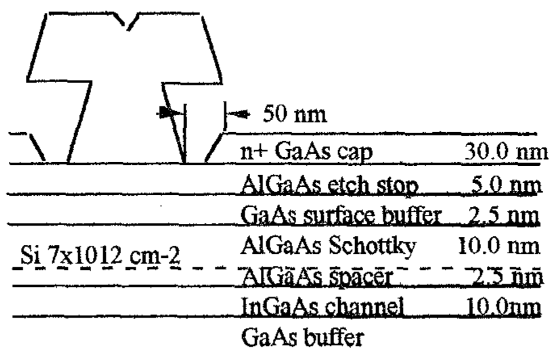

Fig. 1. Structure of the University of Glasgow existing 0.12μm gate length pseudomorphic HEMT.

For the purposes of this investigation, the drift-diffusion module of the commercial device simulator MEDICI [2] is utilised. When compared with Monte Carlo simulations, it has been established that a well calibrated drift-diffusion simulation, including enhanced saturation velocity in the mobility model, can represent accurately the channel velocity and the DC characteristics of deep sub-micron pHEMTs [3].

The drift-diffusion simulations in our study have been carefully calibrated against Monte Carlo simulations and the measured characteristics of 0.12μm gate length pHEMTs. Typical measured and simulated DC output characteristics of the standard pHEMTs are compared in Fig. 2. The average velocities in the pHEMT channel used in the drift-diffusion simulations are obtained from Monte Carlo simulation.

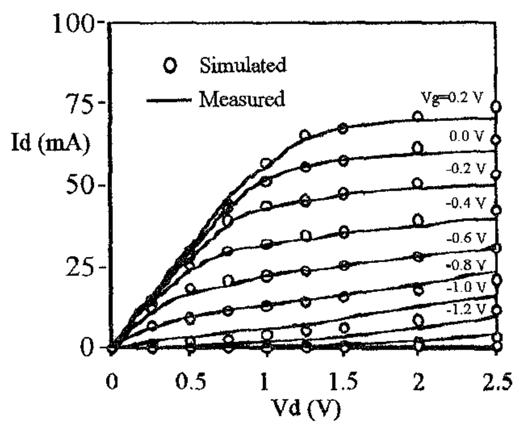

Fig. 2. Comparison of measured and simulated DC I-V curves for the University of Glasgow p-HEMT.

3. The Improved p HEMT

In the first set of simulation based design experiments, the δ-doping layer in the conventional pHEMT was replaced by a uniform channel doping with concentration which reproduces the threshold voltage of the original pHEMT. In order to improve further the linearity, the threshold voltage uniformity and to sharpen the pinch off, a p-doped buffer layer was introduced below the uniformly doped channel in the simulations.

The transconductance with respect to gate bias of the conventional, channel doped and p-buffered pHEMTs are compared in Fig. 3. The channel doped pHEMTs show flatter $g_m(V_{GS})$ response compared to the conventional devices. The introduction of a p-doped buffer results in further improvements in linearity whilst also extending the useful gate voltage range.

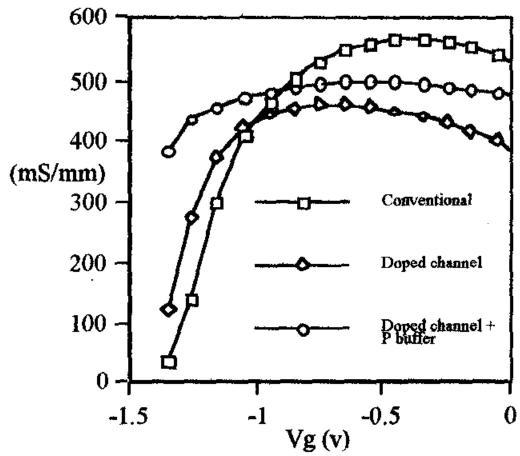

Fig. 3. Simulated transconductance of Conventional and Channel doped p-buffered pHEMTs.

4. Predicted Nonlinear Performance of the Improved HEMT

The transconductance (g_1) data sets generated by the physical model were imported into a numerical package and a tenth order polynomial was fitted to each of the data sets. By differentiating the polynomials, it was possible to obtain the derivatives g_2 and g_3.

By making some simplifying assumptions, it is possible to use the derivatives to approximately calculate the 2-tone 3rd order RF intermodulation distortion performance of each device. It was assumed that

(i) the extrinsic RF transconductance (g_{1rf}) of the device is 10% lower than that of the DC transconductance due to frequency dispersion arising from trapping effects.

(ii) the RF output conductance (g_{dsrf}) of the device is 10% of the RF transconductance (as approximately seen in real sub-micron devices).

(iii) the load impedance is sufficiently small that the nonlinear effects associated with output conductance and can be neglected.

(iv) the amplitude of the applied signal is sufficiently small to allow the use of a Volterra Analysis approach.

(v) the applied signal is clean from all distortion products

This leads to expressions for the 2nd and 3rd order nonlinear voltages at the output

$$R_{Leff} = \frac{R_L}{1 + g_{dsrf} R_L}$$

$$V_{out}(\omega_i) = g_{1rf} R_{Leff} V_{in}(\omega_i)$$

$$V_{out}(\omega_2 \pm \omega_1) = g_{2rf} R_{Leff} V_{in}(\omega_1) V_{in}(\omega_2)$$

$$V_{out}(2\omega_1 \pm \omega_2) = 0.75 g_{3rf} R_{Leff} V_{in}(\omega_1)^2 V_{in}(\omega_2)$$

where R_L is the load resistance. $V_{in}(\omega_i)$ is the peak amplitude of the input signal at frequency ω_i. $V_{out}(\omega_i)$ is the peak amplitude of the output signal at frequency ω_i.

The simulated gain and 3rd order intermodulation distortion of the standard HEMT and the channel doped HEMT with p-doped buffer are shown in Fig. 4. The devices are defined to be 200µm wide working into a 50 Ω load with -16dBm/tone excitation. It can be seen that the improved device gives 10dB reduction of 3rd order distortion over a wide range bias whilst giving comparable gain.

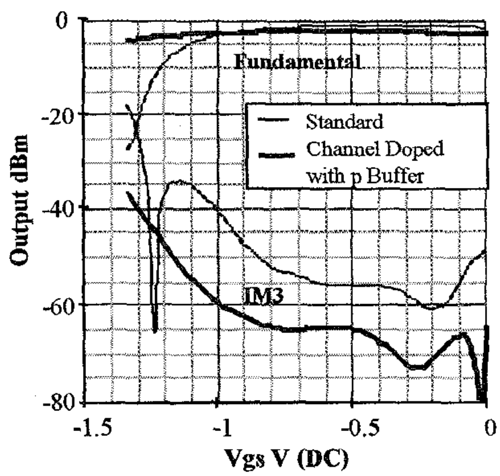

Fig. 4. Simulated bias dependent gain and 3 order intermodulation distortion of the University of Glasgow p-HEMT and the doped channel HEMT. The devices are 200µm wide working into 50 Ω with -16dBm/tone excitation.

Acknowledgements

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