Large-signal model of AlGaAs P-HEMT under optical illumination

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Abstract — As an extension of our previous works in the optical-microwave interaction field, this paper shows the result of the research on large signal dynamic behavior (Pulsed I/V curves) of AlGaAs P-HEMT (pseudomorphic high electron mobility transistor) devices, in the overall I/V plane, when the incident optical input power is changed. A complete bias and optical power dependent of the large signal model for a P-HEMT is determined from experimental scattering parameters, DC and pulsed measurements. All derivatives of the model shown here are continuous for a realistic description of circuit distortion and intermodulation. Experimental results show very good agreement with the theoretical analysis.

Index Terms: Electro-optical model, microwave transistor, P-HEMT, large-signal model.

1. Introduction

The spectacular expansion of optical transmission systems and the increasing use of microwave frequencies within communication systems, coupled with the ability to integrate microwave and optical components into a single wafer usually denominated OMMIC (Optical Microwave Monolithic Integrated Circuit) have stimulated the interest in the development of microwave opto-electronic systems. As far we know, there is not an AlGaAs HEMT model that takes into account these effects, and this is the main reason because our group have interested on the develop of a new electro-optical HEMT model reported in this paper.

A complete nonlinear device model must take into account the different phenomena involved in the nonlinear behavior of the transistor. As in the case of GaAs MESFETs [1], the true large signal behavior [2-3] is governed by the dynamic pulsed I/V characteristics which depend on the quiescent bias point. The results of the study presented here give a complete model of the optical large signal behavior of HEMT devices, along with the knowledge of the optical laws for the most dependent parameters, including the non linear current sources Ids and Igs and the capacitances Cgs and Cds. It is well known that when an AlGaAs HEMT is illuminated by a laser at fixed wavelength, absorption effects take place at the gate-drain and gate-source inter-electrode spaces, and free carrier photo-excitation is induced at the active area level. In fact, these devices, as GaAs MESFETs, exhibit both photoconductive and photovoltaic effects. This means that the static DC curves, as well as the small signal equivalent circuit parameters, change when optical energy is absorbed by the device.

2. Optical Measurements Setup

A detailed optical measurement set-up was reported by our group [4], so here we will only give a brief explanation of the measurement system. The optical source is a laser diode (λ=830 nm), pigtailed to a single-mode optical fiber (diameter = 5 µm). Optical output power varies from 0.01 mW up to 10 mW, and the illumination conditions are obtained for the far field Gaussian profile. The Gaussian beam diameter at the fiber end is Wo=3.1 mm and the diffraction angle is φ=0.085 rad. The optical energy distribution over the PHEMT surface is not uniform, but we can take like the effective region, that where the 90% of the energy density is concentrated. When the distance between the fiber and the device is z = 150 mm, the diameter is 25 mm. We use an x-y-z micro-positionator to adjust the distance between the fiber and the PHEMT surface to 150 mm. The experimental test setup consists of an in-house pulsing system [2] and the above mentioned laser diode, coupled to a CASCADE SUMMIT 9000 microwave wafer probe station. A standard PC computer performs the control of the optical incident power, as well as the pulsing system and the Network Analyzer

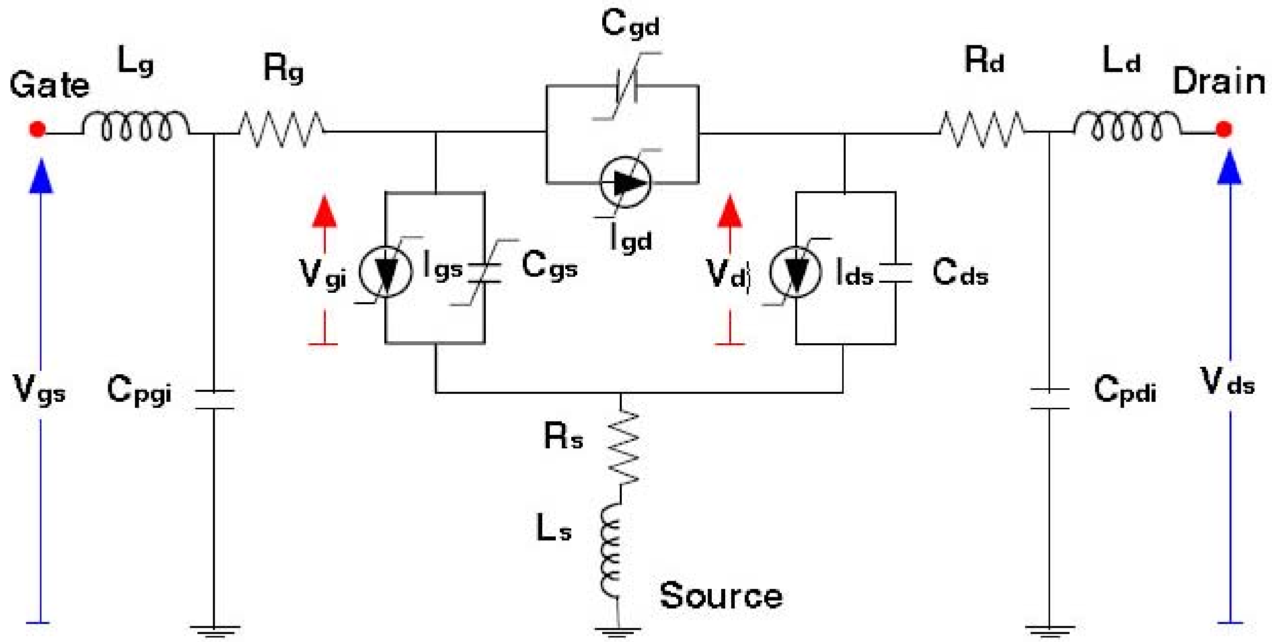

Figure 1. Large Signal equivalent circuit of P-HEMT and GaAs MESFET under Optical Illumination.

HP8510C, used to measure the scattering parameters in the quiescent point. Edge effects were carefully investigated because optical absorption can be dependent on the spot aperture and position.

3. Optical Large Signal Dynamic properties

The equivalent circuit used in Fig. 1 is a rather general one and is applicable to AlGaAs PHEMT and GaAs MESFET devices.

This work uses the MESFET equivalent circuit reported by our group [1] for illuminated devices, with several modifications on the expression of the Ids current source, as well as for non linear Igs source in order to take into account the optical dependence.

The equation for the dynamic current Ids is modified according to Allemando and Bonnaire [5] in order to guarantee the continuity of the derivatives. Therefore, the Ids equation is given by:

$$I_{ds} = I_{dss} \cdot \cdot \left\{ \frac{a \cdot (V_{gi} - V_t) + \log\{2 \cdot \cosh[a \cdot (V_{gi} - V_t)]\}}{2 \cdot b \cdot |V_t|} \right\}^{(E + K_e \cdot V_{gi})}$$

$$\cdot \ (1 + S_s \cdot V_{di}) \ \cdot \tanh\left(\frac{S_l \cdot V_{di}}{1 - K_g \cdot V_{gi}} \right) + C \cdot V_{di} \qquad (1)$$

$$\text{with :} \quad V_t = V_{to} + \gamma \cdot V_{di}$$

where Vgi and Vdi are the internal instantaneous voltages, γ, E, Sl, Kg, a and b are constants, and Idss, Vt0, Ss, Ke, and C are optical power (PL) dependent parameters in order to fit the pulsed I/V dynamic behavior with the optical power applied to the device, as it is shown below

$$\begin{aligned} C &= C_1 \cdot PL \\ Ke &= Ke_0 + Ke_1 \cdot PL \\ Ss &= Ss_0 + Ss_1 \cdot PL^{Ss_2} \\ Vt0 &= Vt0_0 + Vt0_1 \cdot PL^{Vt0_2} + Vt0_3 \cdot PL \\ Idss &= Idss_0 + Idss_1 \cdot PL^{Idss_2} + Idss_3 \cdot PL \end{aligned} \qquad (2)$$

where these new set of parameters, C1, Ke0,Ke1, Ss0, Ss1, Ss2, Vt00,Vt01, Vt02 Vt03, Idss0, Idss1, Idss2 and Idss3 are functions of the quiescent bias point.

The new expression is also valid for GaAs MESFET devices, making the parameters a=b and C=0 only, so this new approach is valid for MESFET and HEMT devices. The non-linear capacitances Cgd and Cgs are modeled by the reported in [4].

Figure 2 shows the measured and modelized static and dynamic I/V curves for a D02AH process 4x30 μm (4 finger by 30 microns gate-width) Philips AlGaAs P-HEMT device. Both curves, static and dynamic, also show, the excellent fit of the model we present in this paper, and they are measured under 10mW of laser illumination power (PL). It can be observed, as could be expected from physical considerations, that there is noticeable change in the drain slopes, along with the normal

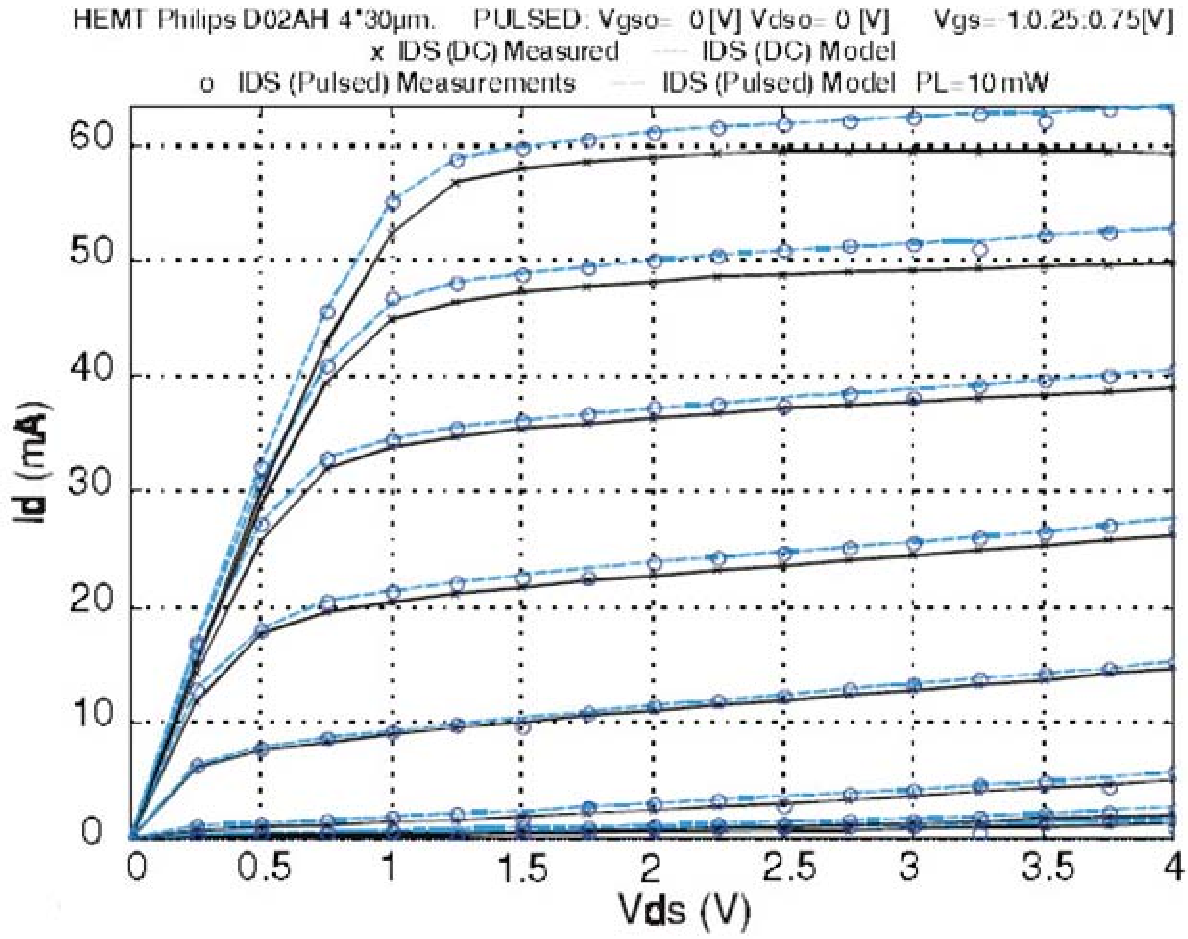

Figure 2. Comparison between measured and modeled static and dynamic I-V curves for a 4*30µm AlGaAs PHEMT.

increment of the drain current.

A new expression to describe the non–linear current source Igs, has been used. This new equation is the sum of two terms: one is the typical Schottky expression valid for the non-illuminated device and the second takes into account the current induced by the optical power:

$$Igs = Igs\big|_{PL=0} + IgsHL = Igs_0 \left(e^{Igs1 \quad Vgi} - 1 \right) + g_1 \cdot e^{g_2 \cdot Vgi} \cdot \left(1 + \frac{g_3 \cdot e^{g_4 \cdot Vgi}}{1 + g_5 \cdot e^{Vdi}} \right) \qquad (3)$$

where g2 and g3 only depend of the device size (gate length) and do not vary with the optical power, but g1, g4 y g5 show polynomial and exponential variations with the applied optical (PL).

Furthermore, we assumed that the Igd current source follows a linear expression. The output capacitance Cds is assumed linear. This expression concludes the explanation of all non-linearities of this new large signal model. Parasitic elements are extracted from multibias scattering measurements using conventional techniques, under the assumption that they do not vary with bias point and optical power. Figure 3 shows a comparison between modeled and measured scattering parameters for a PL=2mW. The simulation has been performed using the model presented in this paper and the ADS simulator from Agilent Technologies.

4. Conclusions

An exhaustive investigation on the dynamic properties of AlGaAs PHEMT devices under optical illumination has been performed. The main dependencies and the way of integrating this behavior into any classical analytical equation for the drain and gate currents has been shown. Numerical simulations show good experimental agreement.

5. Acknowledgement

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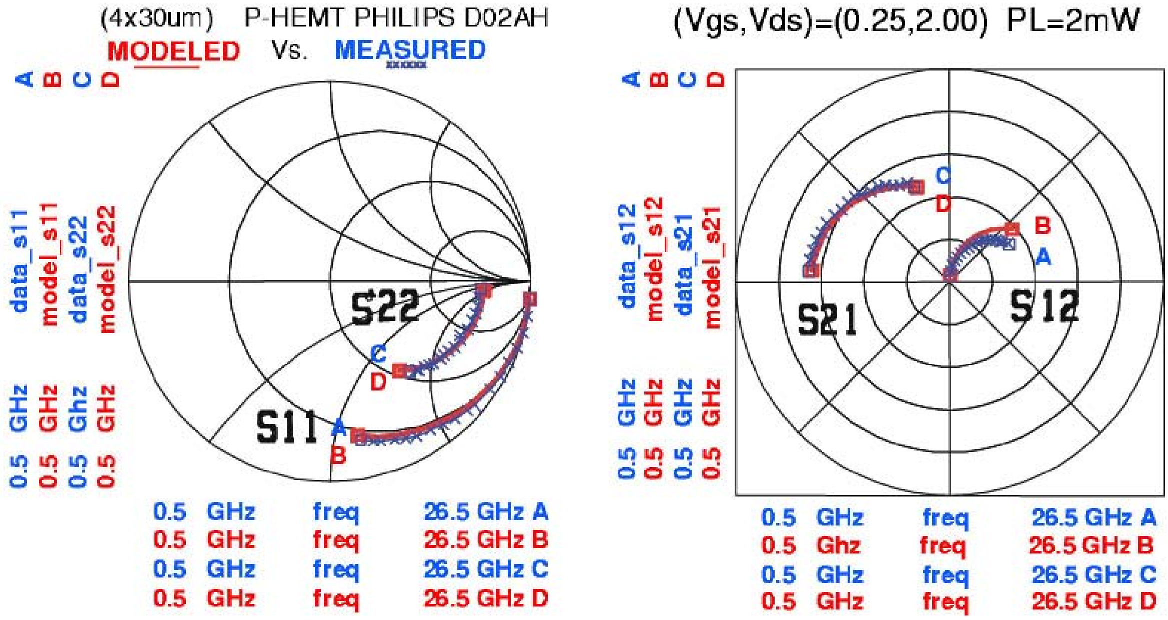

Figure 3. ADS simulator output comparison using our model and measurements of the scattering parameters at Vgs=0.25, Vds=2V and PL=2 mW

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