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The effects of extended depletion region on noise modeling of HEMT's

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Abstract: In this work we have extended the analytical model on noise, by taking into account the effect of the depletion region that extends into the gate to drain spacing. The model utilizes the charge–control model based on analytical functions that relate 2-D electron gas concentration and the Fermi level. The effects of this high field extension region on the noise performance of the device have been investigated. Using the proposed model, the noise characteristics of two HEMTs are analytically calculated and compared with the measured data. It is observed that the contribution of the extended depletion region to the overall device noise is rather significant and it should not be ignored. The theoretical predictions based on the model are found to be in good agreement with the measured noise data.

Keywords: MODFETs, HEMTs, Noise Modeling

Classification: Electron devices

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1 Introduction

It is well known that in a HEMT structure as the gate-length decreases to sub-micron levels, two-dimensional effects of the gate and drain bias voltages become extremely important. These effects arise due to extension of depletion region in the gate to drain spacing [1]. In this paper we have extended Ando and Itoh's noise model [2] by taking into account the effects of the depletion region extension into gate to drain spacing and studying the effects of this extension on the noise performance of the device.

2 Charge Control Model And Small Signal Parameters

In order to calculate the noise performance of a given device, the first step is to calculate the DC characteristics and the small signal equivalent circuit parameters of the device. Next, is to determine the drain and gate noise sources and their correlation coefficient. The third step is to add the extrinsic noise sources and calculate the Noise Figure of the device. For the determination of DC characteristics and small signal parameters, first of all the variation of 2-DEG sheet carrier concentration (n_s) with gate voltage (V_{gs}) and Fermi level (E_f) is calculated. The carrier concentration, n_s is numerically calculated from simultaneous solutions of Schrödinger and Poisson equations by the method used by Ahn and Nokali [3]. Fig. 1 shows the cross-sectional view of the HEMT. The channel can be divided into three regions; L_1 is length of the constant mobility region shown as region I. The high field region is divided into two sub-regions of lengths L_{os} and L_{od} where L_{os} is the high field region below the gate shown as region II and L_{od} lies between the edge of the gate and drain edge shown as region III as was originally suggested in [1].

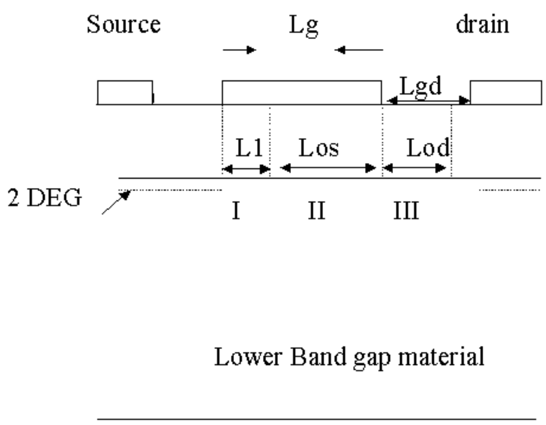

Fig. 1. Cross-sectional view of HEMT.

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Following the analysis given by Ando and Itoh [2] and the approach given in [1], the lengths of the three regions L_1, L_{os} and L_{od} are calculated by solving the two dimension Poisson equation. It is assumed that two sub regions are completely depleted and depletion region between gate and drain is assumed to be rectangular in shape. The boundary conditions assumed are i) there is continuity of potential ii) there is discontinuity of transverse field at hetero-interface due to 2DEG iii) there is discontinuity of surface electric field at the edge of the gate. Using these assumptions and solving Poisson equation following results are obtained [1].

$$\left(\frac{L_{od}}{d}\right)^2 = \frac{E_0}{E_B}\left(e^{\frac{\pi L_{os}}{2d}} - Sinh\left(\frac{\pi L_{os}}{2d}\right)e^{\frac{-\pi L_{od}}{2d}} - 1\right) \tag{1}$$

$d = d_d + d_i$, E_0 is the saturation electric field and

Drain to source voltage V_{DS} can be written as

$$V_{DS} = V(L_1) + V_{DG} + 2dE_0 Sinh\left(\frac{\pi L_{os}}{2d}\right) \tag{2}$$

Where V_{DG} is the channel voltage drop beneath gate to drain depletion region and is given as

$$V_{DG} = 2dE_0 Sinh\left(\pi\frac{L_{os}}{2d}\right)\left(e^{-\frac{\pi L_{0s}}{2d}} - 1\right) + E_0 L_{0d} e^{\frac{\pi L_{os}}{2d}} - \frac{L_{od}^3 E_B}{3d^2} \tag{3}$$

By solving equations (1), (2) and (3) simultaneously the values of L_{os}, L_{od} and L_1 are obtained. Based on the calculated values of L_1, L_{os} and L_{od} the DC Characteristics and small signal equivalent circuit parameters are obtained [1, 2].

Next step in noise modeling is to evaluate the noise sources in the device. Noise is produced in a device both by sources intrinsic to the HEMT device operation and by thermal sources associated with parasitic resistances. We have used approach mentioned in [2] to calculate the noise parameters.

Intrinsic noise arises from two mechanisms: The first one is the thermal noise produced in the ohmic section of the channel i.e. region I. The second is the diffusion noise arising from the velocity saturation region. In our model the high field carrier velocity saturated region is divided into two sub regions viz. one under the gate (region II) and the other between the gate and drain (region III). Previous noise models have assumed [2] that region between the gate and the drain can be taken into consideration by taking the contribution of the region as a lumped resistance. In our calculations we have assumed that region III also contributes to the diffusion noise. Taking L_{od} into account the noise performance of two devices were studied and compared with measured results available in published literature.

3 Results And Discussion

Using the principles mentioned in [1] minimum noise figure was calculated for the AlGaAs/GaAs HEMT device with gate length of 0.3 μm, gate width of 200 μm and doped layer thickness is 250 A. These are the same device

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dimensions considered by Ando and Itoh [2]. The calculations were carried out for drain supply of 2 V. Fig. 2 shows the comparison of experimental results of variation of minimum Noise figure with drain bias current of the device whose parameters are given in [2]. It is observed that if the extended depletion region is not taken into account, satisfactory agreement between the calculated and measured Noise Figure at all bias points can be obtained only by assuming a lower value of saturation velocity for electrons. However, if the noise contribution from the region III i.e. the extended depletion region beyond the gate is also taken into account the Noise Figure at all the bias points agree well with the measured data without unjustifiable choice of low carrier saturation velocity [4].

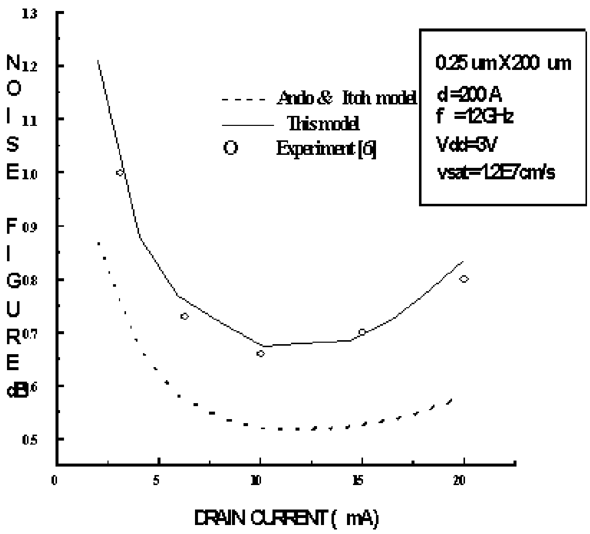

Fig. 2. Comparison of calculated Noise figure data with and without considering the extended region with the measured data.

We also studied the frequency dependence of Noise Figure with and without the extended depletion region taken into account. We calculated the minimum noise figure for the device with gate length of 0.35 μm and gate width of 200 μm [5]. Fig. 3 shows the experimental data of variation of minimum Noise Figure with frequency and its comparison with the simulated data with and without the extension of depletion region taken into account. It is observed that the predicted values of the Noise Figure with the extension of the depletion region taken into account, agree reasonably well with the measured values.

In this way the model has been used to predict accurately the noise performance of two devices reported earlier in the literature. Hence we conclude that the contribution of noise from extended depletion (region III) caused by the two-dimensional effects in short channel HEMTs, is significant and should be taken into account in the calculation of the Noise Figure.

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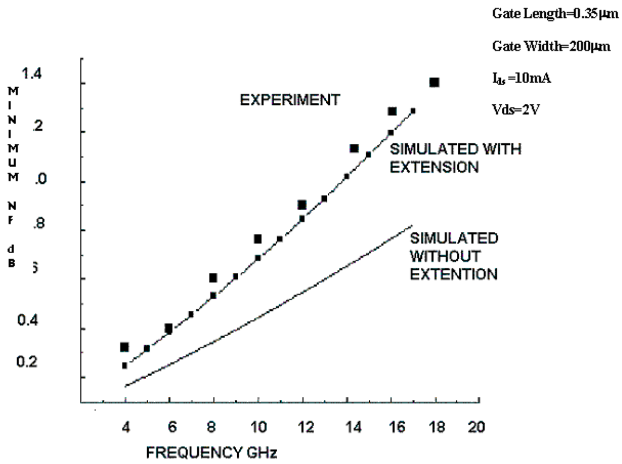

Fig. 3. Comparison of Experimental Results of Variation of Noise Figure versus Frequency with simulated results with and without taking into account of the extension of depletion region.

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