Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 504-505

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Low Frequency Noise Sources in AlGaAs/InGaAs HEMTs

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1. Introduction

AlGaAs/InGaAs HEMT's (High Electron Mobility Transistors) are widely used in the millimeter-wave and optical communication systems because of their excellent high-frequency performance [1]. However, low frequency noise (LFN) in the HEMT's is one of the major limitations on the performance of high-frequency analog circuits [2]. In this study, we investigate the location of the noise source by using the simple model proposed. This model enables us to separate the observed LFN into two kinds of noise sources, i.e., the noise source in the intrinsic region and that in the parasitic region. Furthermore, we show that LFN generated in the parasitic region mainly originats from the tunnel resistance between the cap layer and the channel layer.

2. Experiments

The transistors investigated in this work are AlGaAs/InGaAs HEMT's with various gate length (L_g) ranging from 0.25 μm to 0.95 μm. The gate width (W_g) and gate recess width (L_r) is fixed at 25 μm and 0.4μm, respectively. The gate-to-source spacing (L_{sg}) is varied from 0.4μm to 15.6μm. The noise spectrum density ($S_n(f)$) of the drain current was measured in a frequency range of 10-100 kHz under two kinds of bias conditions. One is that the gate voltage (V_g) was changed from -1.5 V to +0.5 V at the constant drain voltages of 0.1 V in order to clarify the location of the noise source. Another is that V_g was changed at the constant drain current of 500μA. The aim of this measurement is to investigate the origin of LFN generated in the parasitic region.

3. Results and Discussions

Figure 1 shows the dependence of the noise spectrum densities on V_g-V_{th} for devices with different gate length, where V_{th} means the threshold voltage. $S_n(f)$ for all devices rapidly increase with V_g-V_{th} up to 0.1 V, and then decrease gradually. $S_n(f)$ for the short-gate device is higher than that for the long-gate device, especially in the low gate voltage region.

Figure 2 shows the noise model used in this study. In this model, the device is divided into three regions, that is, the intrinsic, source and drain regions. Each region is equivalently expressed by the resistance R_x and the noise current source $i_x(t)$ (x=s,i,d). Using the Hooge relation [3], we can estimate the noise spectrum densities $S_{nx}(f)$ (x=s,i,d) which are defined by the autocorrelation function of $i_x(t)$. Supposing that the correlation between them are negligible, one can obtain the total noise spectrum density $S_n(f)$. The calculations are shown in Fig. 1 by the solid line. The calculations based on our model agree with the experimental results well. Figure 3 shows the contributions of the noise sources in the intrinsic and parasitic regions to the total LFN. The dominant LFN is generated from the intrinsic region in the range of V_g-V_{th}<0.9V while LFN generated from the parasitic region is dominant in another range. In other words, the dominant LFN changes with the gate voltage, so that it becomes possible to investigate the noise sources in the intrinsic and parasitic regions separately.

Figure 4 shows the dependence of $S_n(f)$ on V_g-V_{th} for the devices with various L_{sg}. In this experiments, $S_n(f)$ was measured under the condition of the constant drain current (500μm) in order to clarify the noise source in the parasitic region. The noise spectrum densities for different L_{sg} approximately coincide with each other in the range of low V_g-V_{th} since the dominant noise source is $S_{ni}(f)$ at the bias conditions as mentioned above. On the other hand, the noise spectrum densities depend on L_{sg} in another range of V_g-V_{th}. Figure 5 shows the values of the noise spectrum densities at V_g-V_{th} =1.4 V as a function of L_{sg}. The noise spectrum densities decrease with L_{sg}. This means that the dominant noise source in the parasitic region does not originate from neither R_{rs} nor R_{c1}, where R_{rs} and R_{c1} denote the resistance of the gate recess region and the contact resistance, respectively (see Fig. 6).

In order to investigate the noise source in details, the parameters of transmission line model (TLM) [4] shown in Fig.6 were determined experimentally. Using these parameters, we estimated the spectrum densities of the noise sources located in the cap layer (ρ_1) and the channel layer (ρ_2) can be estimated by means of the Hooge relation. Since the spectrum densities estimated (< 10^{-20} A^2/Hz) are much smaller than the experimental results, one can conclude that the dominant noise source is generated from the resistance between the cap layer and the channel layer (ρ_1 or R_{c2}). Furthermore, the calculations based on the TLM suggests that the dependence of $S_n(f)$ on L_{sg} are caused by the variations in the current path across the parasitic region.

4. Conclusion

We have investigated low frequency noise (LFN) in the AlGaAs/InGaAs HEMT's using simple model proposed. We have succeeded to separate the observed LFN into the noise sources located in the intrinsic and parasitic regions, so that one can estimate these noise sources separately. Furthermore, LFN generated in the parasitic region is investigated on the basis of the Transmission Line Model (TLM). It is found that the tunnel resistance between the cap layer and the channel layer causes the dominant LFN in the parasitic region.

References

[1] P.M.Smith *et al*, IEEE MTT-S Digest, pp. 983-986, 1989.

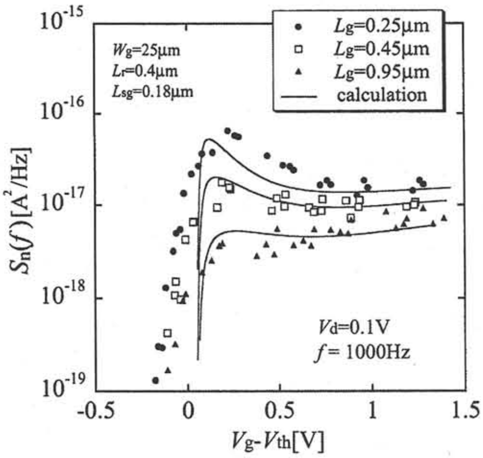

Fig. 1 Noise spectrum densities $S_n(f)$ at 1000 Hz as a function of V_g-V_{th} for the devices with different L_g.

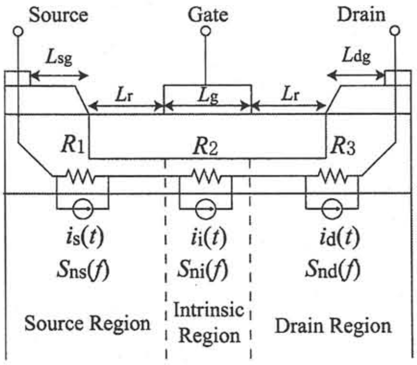

Fig. 2 The noise model used in this study.

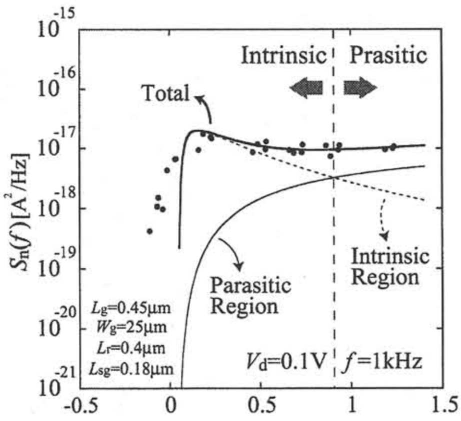

Fig. 3 The contributions of the noise sources located in the intrinsic and parasitic regions to the total LFN.

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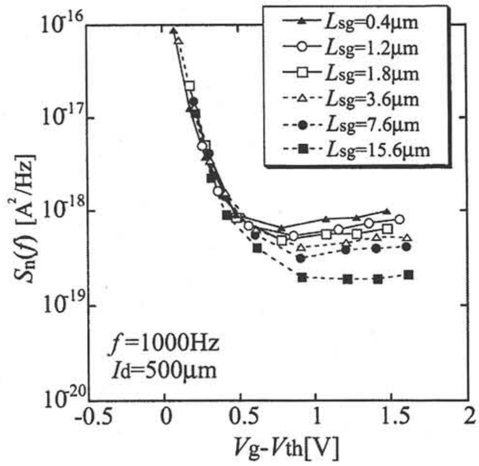

Fig. 4 Dependence of $S_n(f)$ on V_g-V_{th} for several devices with different L_{sg}.

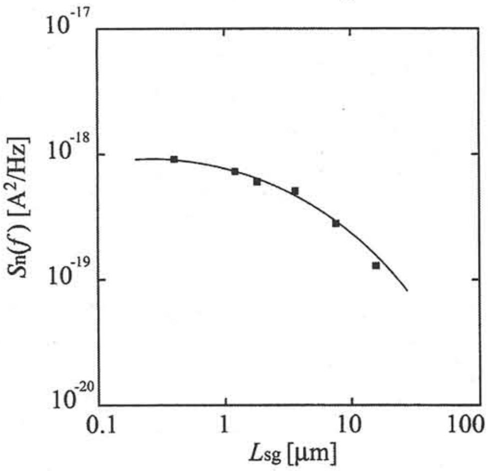

Fig. 5 Noise spectrum densities $S_n(f)$ at V_g-V_{th}=1.4V plotted against L_{sg}.

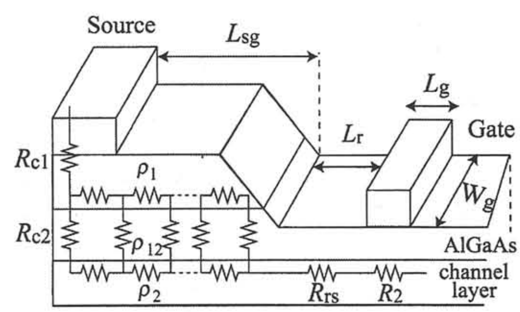

Fig. 6 Transmission Line Model (TLM) proposed by S. J. Lee et al [4]. This model was used in the analysis of LFN generating from the parasitic region.