Low Frequency Noise Sources in AlGaAs/InGaAs HEMTs

S. Nishiyama, T. Iwaki and K. Higuchi
Grad. Sch. of Advanced Sciences of Matter
Hiroshima University, Higashi-Hiroshima, 739-8526 Japan
Phone: +81-824-24-7637 Fax: +81-824-22-7195 E-mail: nisiyama@hiroshima-u.ac.jp

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 originates 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 ($L_{gs}$) 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 $R$, and the noise current source $i_n(x,s,i,d)$. Using the Hooge relation [3], we can estimate the noise spectrum densities $S_{n0}(f)$ ($x=$s,i,d) which are defined by the autocorrelation function of $i_n(f)$. 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 $L_{gs}$. 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 $L_{gs}$ approximately coincide with each other in the range of low $V_g$($V_{th}$ since the dominant noise source is $S_n(f)$ at the bias conditions as mentioned above. On the other hand, the noise spectrum densities depend on $L_{gs}$ 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 $L_{gs}$. The noise spectrum densities decrease with $L_{gs}$. This means that the dominant noise source in the parasitic region does not originate from neither $R_{es}$ nor $R_{s1}$, where $R_{es}$ and $R_{s1}$ 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 ($\rho_1$) and the channel layer ($\rho_2$) can be estimated by means of the Hooge relation. Since the spectrum densities estimated ($< 10^{-30}$ A²/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 ($\rho_1$ or $R_{s1}$). Furthermore, the calculations based on the TLM suggests that the dependence of $S_n(f)$ on $L_{gs}$ 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

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

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.

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.