Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 100-101

F-2-5

Low-Frequency Noise Generated From High-Field Region in AlGaAs/InGaAs HEMTs

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1. Introduction

AlGaAs/InGaAs high electron mobility transistors (HEMTs) are widely used in the millimeter-wave and optical communication systems because of their excellent high-frequency performance [1]. In a nonlinear circuit as a mixer and oscillator, low-frequency noise (LFN) in HEMTs can be up-converted to intermediate or high frequency. Therefore, LFN in HEMTs is one of the major limitations on the performance of high-frequency analog circuits [2]. In such circuits, the applied voltages to HEMTs are always under velocity saturation conditions. Although one can apply the Hooge empirical relation to the low-field region, there are few reports on the LFN generated from the high-field region. In this study, we investigate the LFN generated from the high-field region by using the analysis based on the two-regions model and experiments complementarily.

2. Experiments and Analysis Methods

Figure 1 shows the schematic cross-section of AlGaAs/InGaAs HEMTs investigated in this study. The gate length (L_g) and gate width (W_g) is fixed at 0.15μm and 25μm, respectively. LFN is measured at a frequency of 1kHz, provided that the drain voltage (V_{ds}) is the range from 2V to 4V. The LFN measurement system is the same as one reported in Ref. 3.

In order to analyze the LFN generated from the high-field region, we use the two-regions model [4]. According to the model, the intrinsic region is divided into two regions as shown in Fig. 2. Region 1 stands for the low-field region at the source side, in which the velocity of carriers is proportional to the electric field. Region 2 is the high-field region at the drain side, where the velocity of carriers is saturated. In our analysis, source resistance and drain resistance (R_s, R_d) are taken into account in calculating the drain current and LFN.

The analysis procedure is as follows. First, the LFN generated from the parasitic regions $S_{pa}(f)$ can be directly measured under both low-V_{ds} and high-V_{gs} conditions because the dominant noise is $S_{pa}(f)$ under such conditions [5]. Assuming that no mutual correlation between $S_{pa}(f)$ and the LFN generated from the intrinsic region $S_{int}(f)$, $S_{int}(f)$ can be obtained by subtracting $S_{pa}(f)$ from the measured LFN $S_{id}(f)$. $S_{int}(f)$ consists of three terms, i.e., the LFN generated from the low-field region $S_L(f)$, that from the high-field region $S_H(f)$, and the mutual correlation $S_{LH}(f)$ between them. It is possible to calculate $S_L(f)$ by using the Hooge empirical relation and the length of the low-field region L_1. The length L_1 can be calculated under various voltage conditions with the aid of the two-regions model. Finally, we investigate effects of the high-field region on LFN, $S_H(f)+S_{LH}(f)$, by eliminating $S_L(f)$ from $S_{int}(f)$.

3. Results and Discussions

Figure 3 shows the dependence of spectral noise current density on drain current (I_{ds}) for various V_{gs}. Low drain voltages are applied in these measurements so that one can apply the Hooge empirical relation to $S_{int}(f)$. Under high-V_{gs} conditions, LFN is proportional to about I_{ds}^2 without depending on V_{gs}. This is because $S_{pa}(f)$ is dominant at higher applied gate voltage [5]. From Fig. 3, $S_{pa}(f)$ can be experimentally obtained as

$$S_{pa}(f) = 4.0 \times (I_{ds})^{1.91}. \tag{1}$$

Figure 4 shows the dependence of $S_{id}(f)$ at f=1kHz on V_{gs}-V_{th}, where V_{th} denotes the threshold voltage. The drain voltages applied here are 2V, 2.5V, 3V and 4V, respectively. In this figure, $S_{pa}(f)$ obtained from Eq. (1) is also plotted against V_{gs}-V_{th}. The contribution of $S_{pa}(f)$ to $S_{id}(f)$ increase with V_{gs}-V_{th}. As mentioned above, $S_{int}(f)$ can be obtained as $S_{id}(f)$- $S_{pa}(f)$. The dependence of $S_{int}(f)$ on V_{gs}-V_{th} is shown in Fig. 5 by solid lines. $S_{int}(f)$ for various drain voltages are almost constant irrespective of V_{gs}-V_{th}.

Next, we calculate $S_L(f)$ by using the Hooge empirical relation. $S_L(f)$ is given by

$$S_{L1}(f) = \frac{\alpha_0 \cdot I_{ds}^{\ 2}}{f \cdot n_s \cdot W_g \cdot L_1}, \tag{2}$$

where n_s is the concentration of 2DEG, α_0 is the Hooge parameter (2.0×10^{-3}). The length L_1 is calculated by using the two-regions model. $S_L(f)$ calculated by using Eq. (2) is shown in Fig. 5 by dotted lines. $S_L(f)$ increases with V_{gs}-V_{th} due to the increase in I_{ds}. Since L_1 decreases with V_{ds} (Fig. 6), $S_L(f)$ for V_{ds}=4V is slightly larger than those for other drain voltages. It should be stressed that $S_L(f)$ is larger than $S_{int}(f)$ for V_{gs}-V_{th}>0.2V. This means that $S_{int}(f)$- $S_L(f)$, which contains both $S_H(f)$ and $S_{LH}(f)$, is negative for V_{gs}-V_{th}>0.2V. Figure 7 shows the dependence of $S_H(f)+S_{LH}(f)$ on V_{gs}-V_{th}. Because of $S_H(f)$>0, $S_{LH}(f)$ should be negative for V_{gs}-V_{th}>0.2V. Since $S_H(f)+S_{LH}(f)$ decreases with V_{gs}-V_{th}, the negative correlation increases with V_{gs}-V_{th}. This dependence will be useful to clarify the mechanism of the negative correlation. The analysis on the negative correlation is in progress by means of the two-regions model.

4. Conclusions

In this study, we have investigated the effects of the high-field region on low-frequency noise in AlGaAs/InGaAs HEMTs with the aid of the two-regions model. By using calculations and experiments complementarily, it is found for the first time that the mutual correlation between the LFN generated from the low-field region and that from the high-field region is negative. This negative correlation increases with the gate voltages and cancels out the increase in the LFN generated from the low-field region. The resultant LFN generated from the intrinsic region is almost independent of the gate voltage.

References

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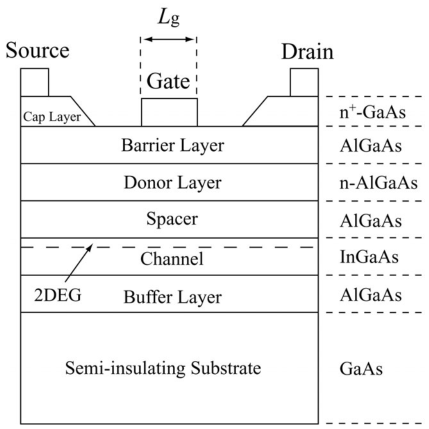

Fig. 1. Schematic cross-sectional view of AlGaAs/InGaAs HEMTs.

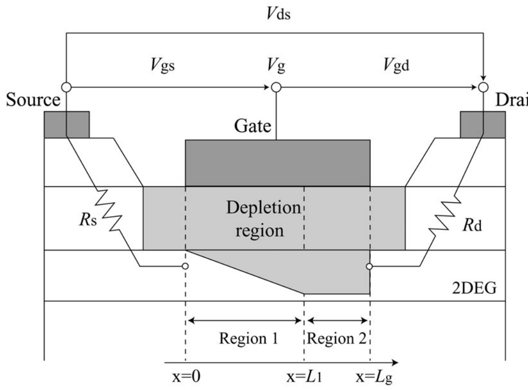

Fig. 2. Two-regions model in HEMTs.

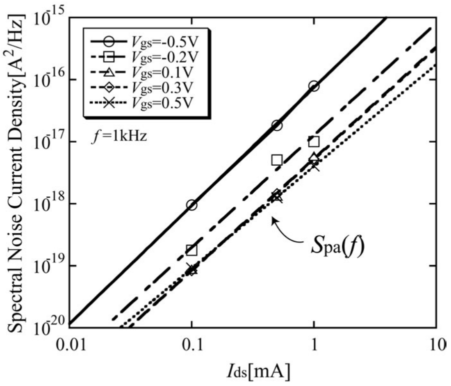

Fig. 3. Dependence of spectral noise current density at f=1kHz on drain current (I_{ds}) for various gate voltages (V_{gs}).

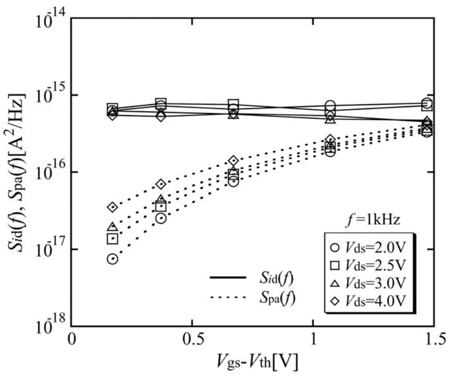

Fig. 4. Dependence of $S_{id}(f)$ and $S_{pa}(f)$ at f=1kHz on V_{gs}-V_{th} for various drain voltages (V_{ds}).

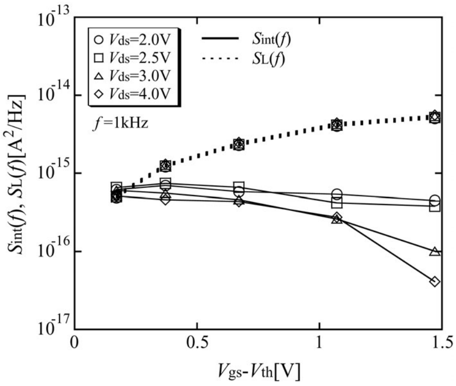

Fig. 5. Dependence of $S_{int}(f)$ and $S_{L1}(f)$ at f=1kHz on V_{gs}-V_{th} for various drain voltages (V_{ds}).

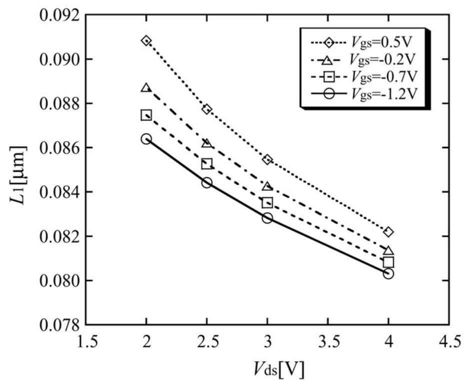

Fig.6 Dependence of the length L_1 on drain voltage (V_{ds}) for various gate voltages (V_{gs}).

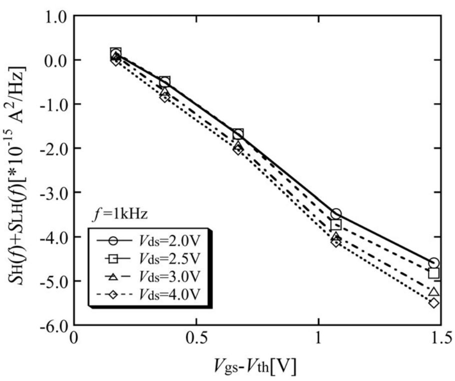

Fig. 7 Dependence of $S_H(f)$+$S_{LH}(f)$ at f=1kHz on V_{gs}-V_{th} for various drain voltages (V_{ds}).