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Low Frequency Noise Caused by Substrate Current 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 order to realize high performance monolithic microwave integrated circuit (MMIC), the thickness of the GaAs substrate is reduced to 40-100 μ m. However, low frequency noise (LFN) in HEMT is one of the major limitations on the performance of high-frequency analog circuits [2]. The reduction of the substrate thickness leads to the increase of the leakage current through the substrate, which possibly causes the additional LFN [3]. In this study, we investigate the relation between the substrate current and LFN. Furthermore, we discuss the limitation of the substrate thickness from the viewpoint of LFN.

2. Experiments

The transistors investigated in this study are AlGaAs/InGaAs HEMTs. The substrate thickness (d_{sub}) is 80μm. The gate length (L_g) and gate width (W_g) is fixed at 0.1μm and 25μm, respectively. In order to observe surplus LFN caused by the substrate current (I_b), it is necessary to separate LFN generated in the channel from LFN measured. For this purpose, LFN is measured with keeping the drain current constant (5mA). This method enables us to keep LFN generated in the channel constant, so that we can obtain the surplus LFN caused by the substrate current. Both LFN and the substrate current are measured, provided that the drain voltage (V_d) and the substrate voltage (V_b) are changed from 0V to +3V and from 0V to -10V, respectively.

3. Substrate Current

Figure 1 shows the dependence of I_b on V_d for V_b=-5V. The broken line indicates the current component injected directly from the drain electrode into the semi-insulating substrate. The substrate current rapidly increases around V_d=2V. This rapid increase of the substrate current is attributed to impact ionization in the channel. This means that some of holes generated by impact ionization are injected into the semi-insulating substrate if negative V_b is applied. Figure 2 shows the experimental data for other substrate voltages. Just as shown in Fig. 1, the current component caused by impact ionization is observed at higher applied voltages. Due to the increase of the current component injected directly from the drain electrode into the semi-insulating substrate, I_b increase with V_b monotonically.

4. LFN and Substrate Current

Figure 3 shows the experimental data of LFN at f=100Hz, provided that the drain current is kept constant (5mA). LFN increases with V_d and V_b. The surplus LFN is observed at the high V_d (>2V). Comparing Fig. 2 to Fig. 3, it is supposed that the increases of LFN with V_b are attributed to the current component being injected directly from the drain electrode into the semi-insulating substrate. Furthermore, the increases of LFN with V_d are apparently due to the increase of the current component caused by impact ionization. Figure 4 shows LFN at f=100Hz as a function of the substrate current. If I_b is less than 5×10^{-10}A, LFN is constant. LFN rapidly increases with I_b in the high substrate current region. Note that LFN contains both noise components caused by the substrate current and generated in the channel. Hereafter, these noise components are denoted by $S_{ib}(f)$ and $S_{ch}(f)$, respectively. In order to obtain the relation between $S_{ib}(f)$ and I_b, it is necessary to eliminate $S_{ch}(f)$ from the total LFN. In these measurements, the drain current is kept constant, which leads to the constant $S_{ch}(f)$. The constant LFN observed for $I_b<5\times10^{-10}$A can be regarded as $S_{ch}(f)$. Therefore if there is no correlation between $S_{ch}(f)$ and $S_{ib}(f)$, the following relation can be obtained;

$$S_{ib}(f) = S_{id}(f) - S_{ch}(f) \quad , \qquad (1)$$

where $S_{id}(f)$ is the total LFN observed. Figure 5 shows the relation between I_b and $S_{ib}(f)$ which are calculated by Eq (1). It is found that $S_{ib}(f)$ is proportional to I_b^2, i.e.,

$$S_{ib}(f) \propto I_b^{\,2} . \qquad (2)$$

This means that the increase of LFN observed in Fig. 3 depends on the substrate current. The relation (2) suggests that the surplus noise $S_{ib}(f)$ is caused by the fluctuation of the channel potential.

5. Limit of Substrate Thickness

On the basis of the knowledge about the surplus noise caused by the substrate current, we consider the restrictions on the substrate thickness from the viewpoint of LFN. Suppose that $S_{ib}(f)$ is not negligible if $S_{ib}(f)$ is more than $S_{ch}(f)$/10. For example, $S_{ch}(f)$ is 4.13×10^{-15} A^2/Hz at I_d=5mA as shown in Fig. 4. Thus, $S_{ib}(f)$ is not negligible under the condition of $I_b>4.41\times10^{-10}$A (see Fig. 5). Since the substrate current is inversely proportional to the substrate thickness as shown in Fig. 6, the substrate thickness should be less than 20μm so as to satisfy the condition of $I_b>4.41\times10^{-10}$A. This means that LFN caused by the substrate current becomes significant if the substrate thickness is less than 20μm. Similarly, under other drain current conditions, the restriction on the substrate thickness can be obtained.

The restriction will give the guideline in respect to the substrate thickness.

6. Conclusions

The substrate current for HEMT increases as the substrate voltages and the drain voltages are applied. In particular, the substrate current increases further at higher drain voltages due to impact ionization. The surplus LFN caused by the substrate current is observed. This LFN increases in proportion to the square of the substrate current, which suggests that the surplus noise is due to the fluctuation of the channel potential caused by the substrate current. Furthermore, by means of the knowledge about the surplus noise, we give a brief discussion concerning with the restriction of substrate thickness from the viewpoint of LFN. The restriction will give useful information to determine the substrate thickness of MMICs.

References

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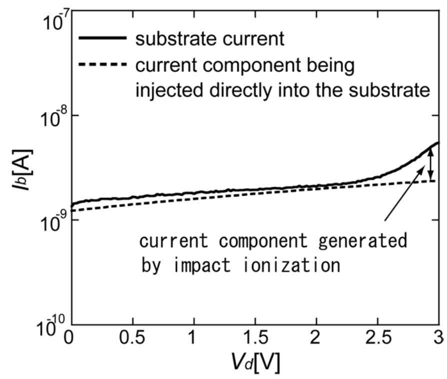

Fig.1 Substrate current as a function of drain voltage.

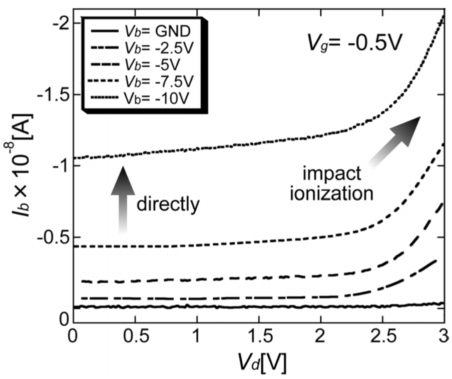

Fig.2 Dependence of the substrate current on the drain voltage for various substrate voltages.

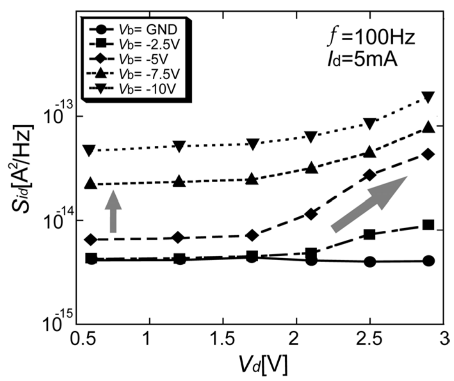

Fig.3 The relation between LFN and the drain voltage.

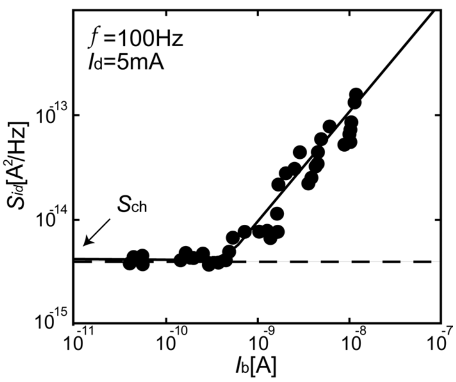

Fig.4 Dependence of LFN on the substrate current.

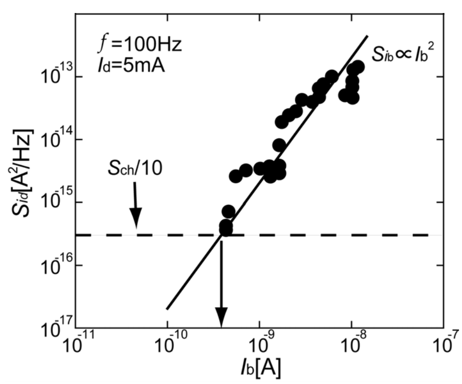

Fig.5 The relation between LFN caused by the substrate current and the substrate current.

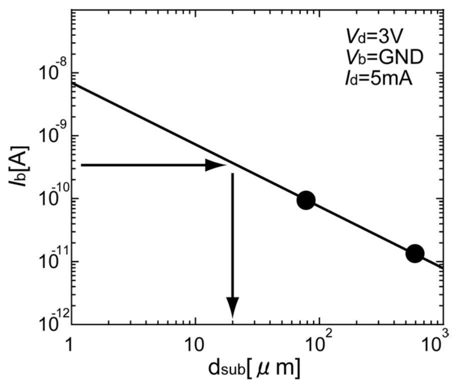

Fig.6 Dependence of the substrate current on the substrate thickness.