Noise Analysis of AlGaN/GaN MOS-HFETs with Photochemical-Vapor Deposition SiO₂ Layer

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Abstract

The noises of AlGaN/GaN metal-oxide semiconductor heterostructure field-effect transistors (MOS-HFETs) and HFETs were investigated as functions of gate voltage and the drain-source distance in the low-drain bias. The normalized noise-power densities of the two HFETs were both proportional to \( V_{gs}^{-1} \) when the devices were biased at \(-4 \text{V} < V_{gs} < 0 \text{V} \) and were independent of the gate voltage when the devices were biased at \( V_{gs} > 0 \text{V} \). Moreover, the normalized noise-power densities of both devices were reversely proportional to the drain-source distance when \( V_{gs} > 0 \text{V} \). Also, all the experiment data can be well explained by Hooge’s Law.

1. Introduction

Previously, we have shown that photochemical-vapor deposition (photo-CVD), using the deuterium (D₂) lamp as the excitation source, can grow high-quality SiO₂ layers used as the gate-oxide layers in nitride-based metal-oxide-semiconductor HFETs (MOS-HFETs)¹⁻³.

However, the low-frequency noise is one of the most important parameters of microwave devices. In this study, nitride-based metal-oxide-semiconductor heterostructure field-effect transistors (MOS-HFETs) and heterostructure field-effect transistors (HFETs) were both fabricated. The low-frequency noises of the fabricated devices were investigated and reported as functions of gate voltage and drain-source distance in the low drain-bias region.

2. Experiment

The structures of AlGaN/GaN MOS-HFETs and HFETs used in this study were all grown on c-face (0001) 2-inch sapphire (Al₂O₃) substrates by metalorganic chemical-vapor deposition (MOCVD). The structures consist of a 30-nm-thick low-temperature GaN nucleation layer, a 2-µm-thick unintentionally-doped GaN layer, a 5-nm-thick unintentionally-doped Al₀.₂₂Ga₀.₇₈N spacer layer, a 15-nm-thick Si-doped Al₀.₁₂Ga₀.₈₈N carrier-supplying layer \( (n = 5 \times 10^{18} \text{cm}^{-3}) \) and a 4-nm-thick unintentionally doped Al₀.₃₂Ga₀.₆₈N cap layer. For comparison, AlGaN/GaN HFETs, with exactly the same device structure, but without the photo-CVD oxide layer, were also fabricated.

3. Results and Discussion

A. The Effect of Gate Voltage at \( V_{ds} = 3 \text{V} \):

Fig. 1(a) and 1(b) show measured room-temperature-normalized noise spectra of the fabricated MOS-HFETs and HFETs, respectively, in low-drain-bias regions. Figures 2(a) and 2(b) show normalized noise-power densities as functions of gate voltage \( V_{gs} \) (Fig. 2(a) \( V_{gs} < 0 \text{V} \), 2(b) \( V_{gs} > 0 \text{V} \)) for the fabricated MOS-HFET and HFET biased at low drain voltage. Insert Fig. 2(a) and 2(b) show total channel resistance as functions of gate voltage.

B. The Effect of Drain-Source Distances for \( V_{gs} \geq 0 \text{V} \)

The normalized low frequency noise spectra of our fabricated MOS-HFETs and HFETs can all be reasonably well fitted by the 1/f law up to 1 kHz when devices were biased at linear region (i.e. \( V_{gs} = 0 \text{V} \), \( V_{ds} = 3 \text{V} \)). Fig. 3(a) and 3(b) show measured room temperature normalized noise spectra of the fabricated MOS-HFETs and HFETs, respectively, for different drain-source distance at \( V_{gs} = 0 \text{V} \). It was found that the normalized noise-power densities of both devices were reversely proportional to the drain-source distance. Previously, we have demonstrated that the low-frequency noises of our MOS-HFETs and HFETs were dominated by the parasitic series resistance \( (R_s) \) when devices were biased before pinch-off region. It can be seen clearly that all these spectra can be fitted reasonably well by the 1/L (L:drain-source distance) curve up to 1 kHz. Moreover, it can also be clearly seen that these theoretical equations agree very well with the experimental results. Such a result again supports the assumption that total resistance \( (R_{total}) \) was dominated by series resistance \( (R_s) \) before device pinch-off.

4. Summary

The low-frequency noises of AlGaN/GaN metal-oxide semiconductor heterostructure field-effect transistors (MOS-HFETs) and heterostructure field-effect transistors (HFETs) were investigated as functions of the gate voltage and drain-source distance at low drain bias. At low drain bias, it was found that the measured noise spectra can fit well by the 1/f law up to 10 kHz. At 100 Hz, the normalized noise-power densities of the two HFETs were both proportional to \( V_{gs}^{-1} \) when the devices were biased at \(-4 \text{V} < V_{gs} < 0 \text{V} \), and were independent of the gate voltage when the devices were biased at \( V_{gs} > 0 \text{V} \). For the effect of each drain-source distance, it was found that the normalized noise-power densities of both devices were reversely proportional to the drain-source distance.
proportional to the drain-source distance. Moreover, all the experiment data of the above two bias conditions can be explained well by noise theory and Hooge’s law.

References

Fig. 1(a) Normalized-noise spectra of the fabricated MOS-HFETs.

Fig. 1(b) Normalized-noise spectra of the fabricated HFETs.

Fig. 2(a) Normalized noise-power densities as functions of gate voltage ($V_{gs}$) biased at low drain voltage, $V_{ds} < 0$ V.

Fig. 2(b) Normalized noise-power densities as functions of gate voltage ($V_{gs}$) biased at low drain voltage, $V_{gs} > 0$ V.

Fig. 3(a) Normalized-noise spectra of the MOS-HFETs for different drain-source distance at different frequencies.

Fig. 3(b) Normalized-noise spectra of the HFETs for different drain-source distance at different frequencies.