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High frequency and low frequency noise of AlGaN/GaN metal-oxide-semiconductor high-electron mobility transistors with gate insulator grown using photoelectrochemical oxidation method

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Recently, GaN-based semiconductors are widely used in electronic evices and optoelectronic devices owing to their high-electron mobility, wide and direct energy bandgap, better thermal and chemical stability. Metal-semiconductor field-effect transistors and metal-semiconductor high-electron mobility field-effect transistors using Schottky gate have been used in high-frequency applications successfully. Those devices have some disadvantages such as large gate leakage current and small breakdown voltage when they are applied in high-power applications. Therefore, the metal-oxide-semiconductor high-electron mobility field-effect transistors (MOS-HEMTs) have better performances in high-frequency and high-power applications.

Up to now, several dielectrics have been used for gate insulators of GaN-based metal-oxide-semiconductor high-electron mobility field-effect transistors. In Si-based MOS devices and integrated circuits, using wet oxidation method or dry oxidation method can obtain high quality SiO_2 films and SiO_2/Si interfaces on Si wafers directly. To obtain high quality insulators and interfaces at insulator/ GaN-based semiconductors, growing oxide films on GaN-based semiconductors surface directly would be a promising method to fabricate high performance GaN-based metal-oxide-semiconductor devices.

Photoelectrochemical (PEC) oxidation method has been used to oxidize GaN-based semiconductors directly to form oxide films successfully. In addition to high quality oxide films and oxide/ semiconductors interfaces, the dc performances of related GaN-based MOS devices and MOS-HEMTs have been reported recently. In this study, we measured and analyzed the high frequency performances and low frequency noise at large drain-source bias of AlGaN/GaN MOS-HEMTs with gate insulators grown using PEC oxidation method.

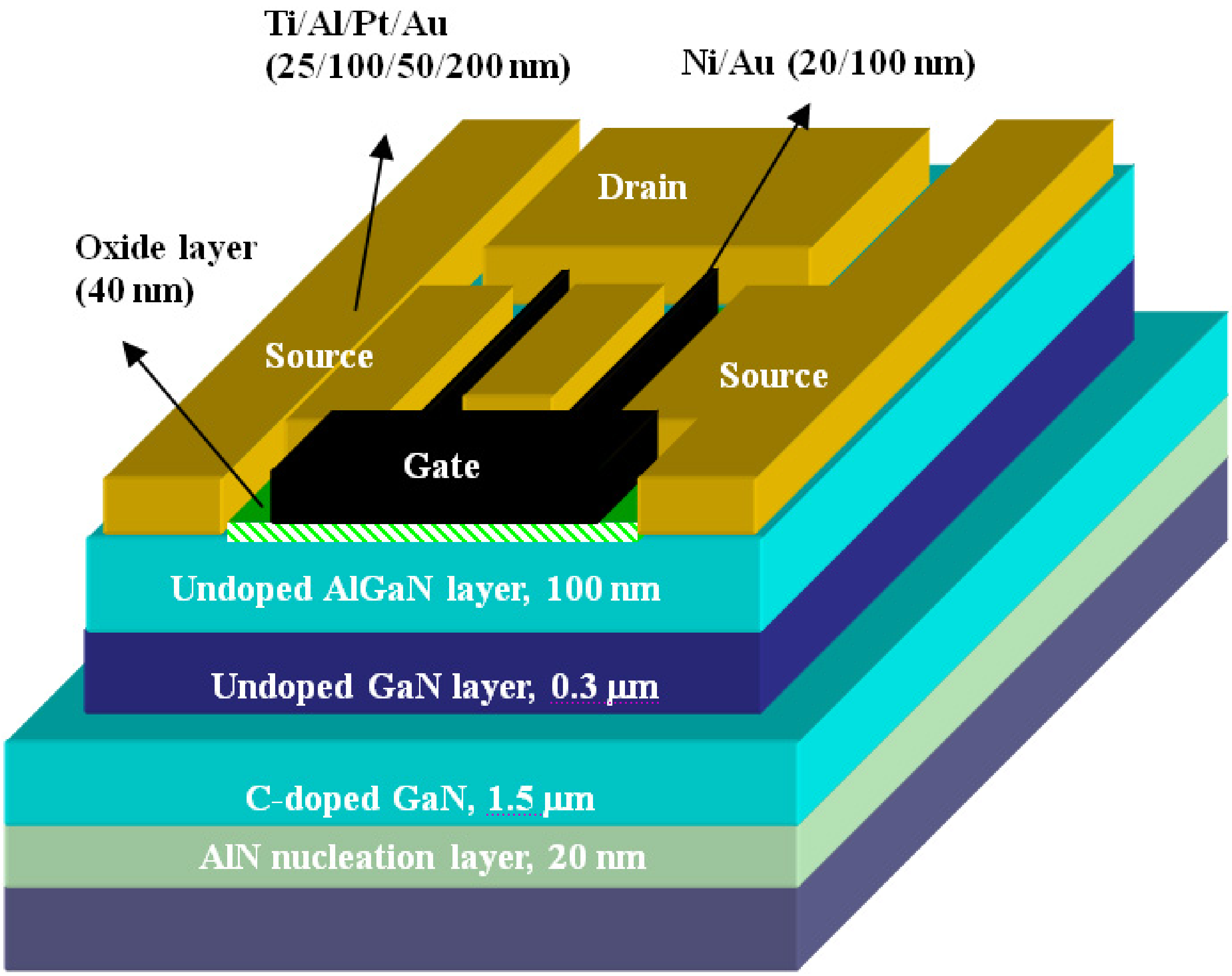

Figure 1. The schematic configuration of AlGaN/GaN MOS-HEMTs.

Figure 1 shows the schematic configuration of $Al_{0.15}Ga_{0.85}N$/GaN HEMTs epitaxial structure used in this study. First, the reactive ion etching system and Ni/Au metal mask were used to perform mesa patterns. Before depositing Ti/Al/Pt/Au (25/100/50/200 nm) as ohmic metals, surface sulfide-treatment was used to remove native oxide films on AlGaN surface. The ohmic contacts were performed at 850 ˚ C in N_2 ambient for 2 mins using rapid thermal annealing system. Then, the PEC oxidation method was used to grow insulators between source and drain regions for gate insulation and surface passivation. The as-grown oxide films do not dissolve in developer, alkaloid solutions and acid solutions and are suitable for the following device process after annealed at 700 ˚ C in O_2 ambient for 2 hrs. The thickness and interface-state density of the annealed oxide films was 40 nm and 5.1×10^{11} $cm^{-2}eV^{-1}$, respectively. Finally, 1- μ m-long and 50- μ m-wide two-finger Ni/Au (20/100 nm) were deposited as gate metals (GSG forms).

Fig. 2 shows the drain-source current-voltage characteristics at different gate-source biases and the transfer characteristics. The saturation current at V_{GS}=0 V is 580 mA/mm and the threshold voltage is –9 V. The maximum extrinsic transconductance ($g_{m(max)}$) of 76.72 mS/mm was obtained at V_{DS}=10 V and V_{GS}=–5.1 V. The forward breakdown voltage and reverse breakdown voltage was 25 V and larger than −100 V. The gate leakage current was only 960 nA and 102 nA when V_{GS}= 20 V and −60 V.

The current gain and maximum available power gain derived from s-parameter measurement as a function of frequency of AlGaN/GaN MOS-HEMTs were shown in Fig. 3. The f_T=5.6 GHz and f_{max}=10.6 GHz were obtained when V_{DS}=10 V.

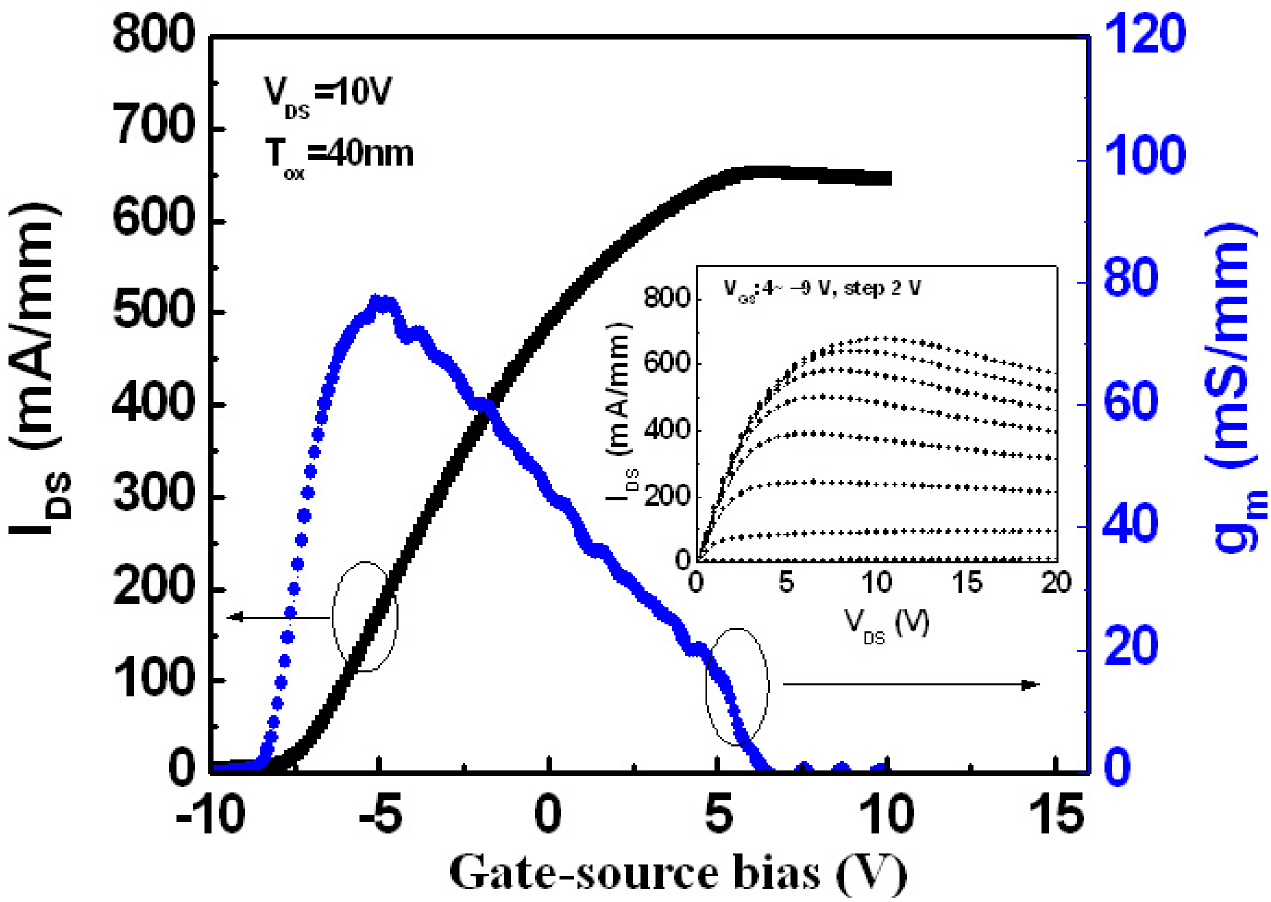

Figure 2. The drain-source current-voltage characteristics under various gate-source biases and the transfer characteristics of AlGaN/GaN MOS-HEMTs.

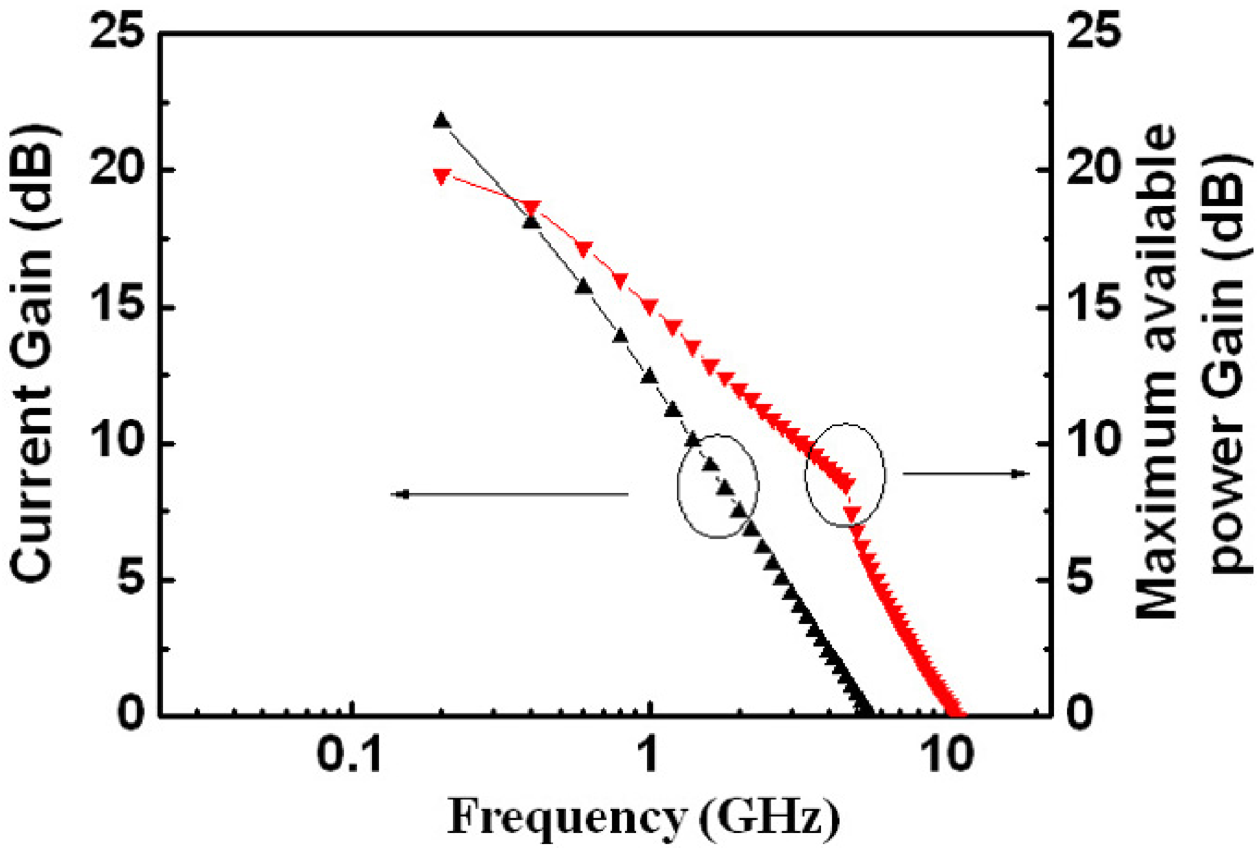

Figure 3. The current gain and maximum available power gain as a function of frequency derived from S-parameter measurement.

The low frequency noise of AlGaN/GaN MOS-HEMTs operated at V_{DS}=10 V was measured at room temperature with the frequency range from 4 Hz to 10 kHz and the gate-source voltage varied from −8 V to 0 V (by a step of 2 V). Figure 4 shows the normalized noise power spectra and they were fitted well by 1/f law. Using mobility fluctuation model, the Hooge's coefficient (α) can be estimated from equation (1) as following:

$$\alpha = S_I(f) \times f \times N/I^2 = [S_I(f) \times f \times (L_g^2/q \times \mu \times R_{ch})]/I^2 \qquad (1)$$

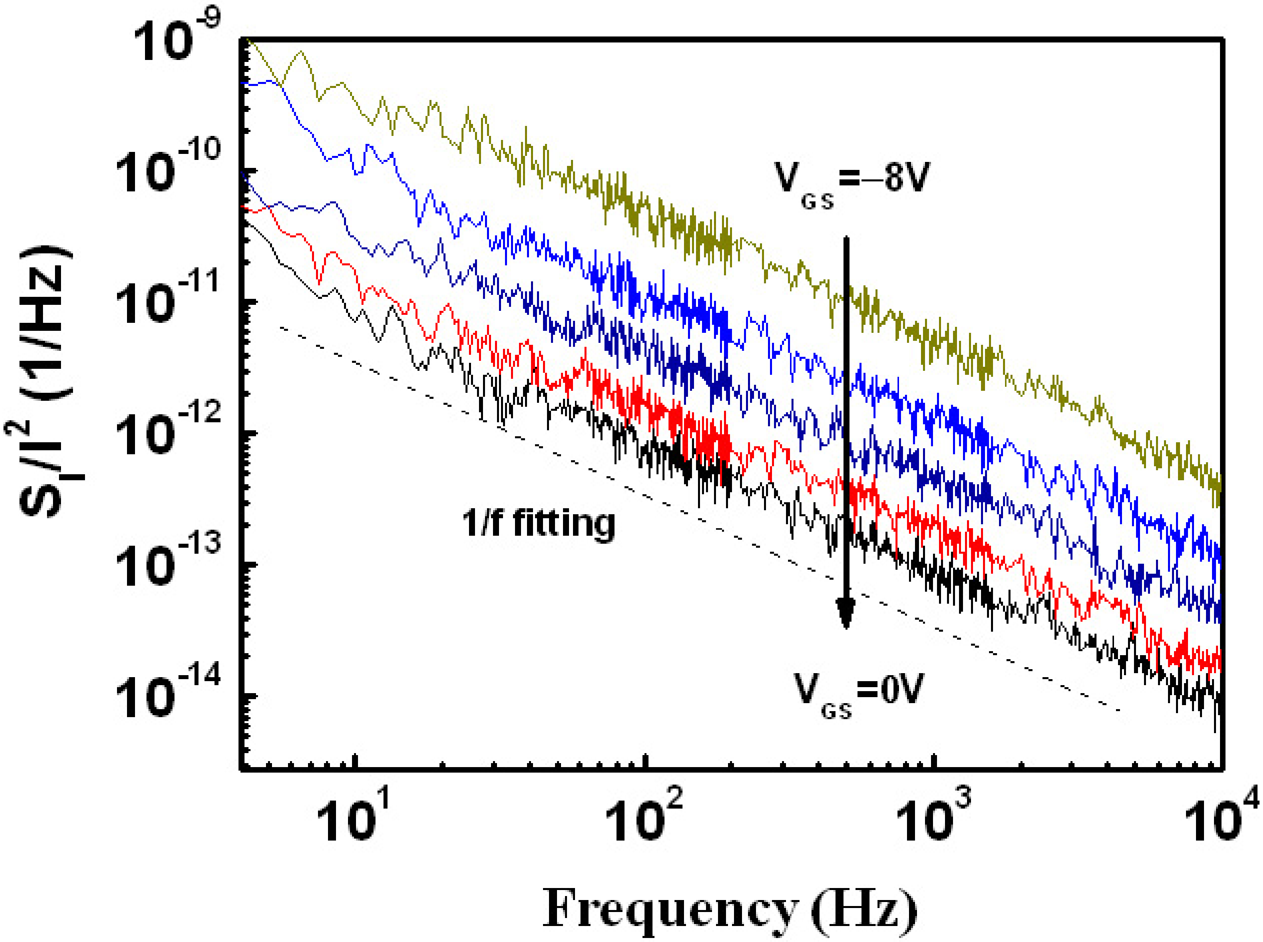

Figure 4. The normalized noise power spectra in saturation of AlGaN/GaN MOS-HEMTs.

where $S_I(f)$ is the noise power density, f is the frequency, I is the drain-source current, L_g is the gate length, μ is carrier mobility, R_{ch} is channel resistance. The $\alpha=1.25\times10^{-3}$ was estimated at 100 Hz when MOS-HEMTs operated at V_{DS}=10 V and V_{GS}=0 V. As shown in Fig. 4, the normalized noise power densities increased when gate-source bias decreased. Owing to the gate leakage current is five orders of magnitude smaller than drain-source current and the specific contact resistance is only 8.7×10^{-6} Ω-cm^2, the low frequency noise was dominated by bulk noise in our MOS-HEMTs. The total noise can be expressed as equation (2):

$$S_{Rt}=S_{Rch}+S_{Rs} \qquad (2)$$

where S_{Rt} is total noise, S_{Rch} is the noise originated from channel under gate, S_{Rs} is the noise originated from un-gated region. The total resistance can be expressed as equation (3):

$$R_t = R_s + R_{ch} = R_s+L_g|V_{off}|/(Wq\mu n_{ch}V_G) \qquad (3)$$

where R_t is total resistance, R_s is the resistance of the un-gated region, R_{ch} is the channel resistance, L_g is the gate length, V_{off} is the cutoff frequency, W is the gate width, μ is carrier mobility, n_{ch} is the concentration of 2DEG at V_{GS}=0 V, $V_G=V_{GS}-V_{off}$ is the effective gate bias. When gate-source bias is negative, the bulk noise was dominated by the channel noise because the R_{ch} is larger than R_s. The total low frequency noise can be expressed as following:

$$S_I(f)/I^2 = S_{Rt}/R_t^2 = (S_{Rch}+S_{Rs})/(R_{ch}+R_s)^2 \cong S_{Rch}/R_{ch}^2 \qquad (4)$$

$$S_I(f)/I_2 = \alpha/fN \propto V_G^{-1} \qquad (5)$$

According to the equations mentioned above, it can explain that the normalized noise power densities increased as gate-source bias decreased.

In this work, we fabricated AlGaN/GaN MOS-HEMTs with gate insulators grown using PEC oxidation method. The saturation current at V_{GS}=0 V and maximum extrinsic transconductance is 580 mA/mm is 76.72 mS/mm, respectively. The forward breakdown voltage and reverse breakdown voltage is 25 V and larger than -100 V, respectively. The f_T and f_{max} is 5.6 GHz and 10.6 GHz, respectively. The low frequency noise of AlGaN/GaN MOS-HEMTs can be fitted well by 1/f law. The Hooge's coefficient of 1.25×10^{-3} was estimated at 100 Hz when MOS-HEMTs were operated at V_{DS}=10 V and V_{GS}=0 V. According to those data, the PEC oxidation method can be expected a promising method to fabricate high performance GaN-based MOS devices and integrated circuits.