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AlGaN/GaN MIS-HEMTs Fabricated Using SiN/SiO_2/SiN Triple-Layer Insulators

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1. Introduction

AlGaN/GaN high electron mobility transistors (HEMTs) are devices that can operate at high power, at high speed and in a high-temperature environment. In particular, to achieve millimeter-wave (30 to 300 GHz) operation, we fabricated sub-50-nm-gate HEMTs [1]. In addition to reducing the gate length L_g, we performed rapid thermal annealing (RTA) of the fabricated HEMTs to improve their Schottky gate contacts [2]. The RTA process reduces the interface traps between the gate electrode and the AlGaN layer. On the other hand, it is well known that the AlGaN surface is stabilized by passivation using SiN films [3]. In this work, we proposed and fabricated AlGaN/GaN metal-insulator-semiconductor (MIS) HEMTs using SiN/SiO_2/SiN triple-layer insulators. The proposed MIS-HEMTs have the following advantages: The surface is stabilized; the T-shaped gate is mechanically stable in the sub-50-nm-gate region; the region around the gate foot is free from damage during the dry etching process.

2. Fabrication Process

A schematic cross-section of the fabricated MIS-HEMT is shown in Fig. 1. The HEMT epitaxial layers were grown on (0001) SiC substrates by metal organic chemical vapor deposition (MOCVD). The layers were 2-μm GaN and 18-nm $Al_{0.21}Ga_{0.79}N$. Both layers were not intentionally doped. Hall measurements showed a two-dimensional electron gas (2DEG) sheet density N_s of 7.7×10^{12} cm^{-2}, a 2DEG mobility μ of 1690 cm^2/Vs and a sheet resistance R_{sheet} of 480 Ω/square at room temperature.

The fabrication process was similar to that used in our previous works [1,2]. First, the bottom SiN film, which acts as an insulator layer of the MIS-HEMT, was deposited on the AlGaN layer by hot wire chemical vapor deposition. Note that R_{sheet} was unchanged before and after the deposition of the SiN film. Source and drain ohmic contacts were formed using alloyed Ti/Al. The source-drain spacing L_{sd} was 2 μm. T-shaped Ti/Pt/Au Schottky gates with widths W_g of 50×2 μm were fabricated with electron beam (EB) lithography and a standard lift-off technique. SiO_2 and SiN films were deposited on the bottom SiN film. A T-shaped gate pattern was directly written by EB exposure after coating with a triple-layer EB resist (ZEP/PMGI/ZEP). The bottom of the T-shaped gate pattern was replicated on the topmost SiN film by reactive ion etching (RIE) with CF_4 gas. The SiO_2 film, which was damaged during the RIE process, was wet-chemically etched. Lastly, the Ti/Pt/Au gate metal was evaporated and lifted off. The topmost SiN film acts as a support for the T-shaped gate.

3. Device Performance

On-wafer DC and RF measurements were carried out at room temperature. Figure 2 shows the current-voltage (*I-V*) characteristics of a 45-nm-gate HEMT. This HEMT is well

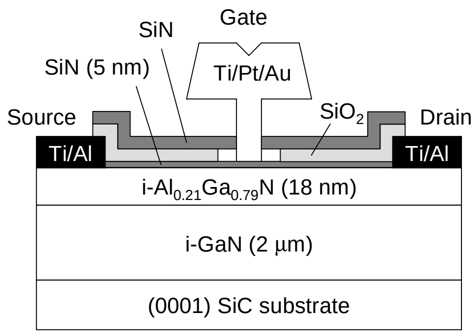

Fig. 1 Schematic cross-section of a fabricated AlGaN/GaN MIS-HEMT.

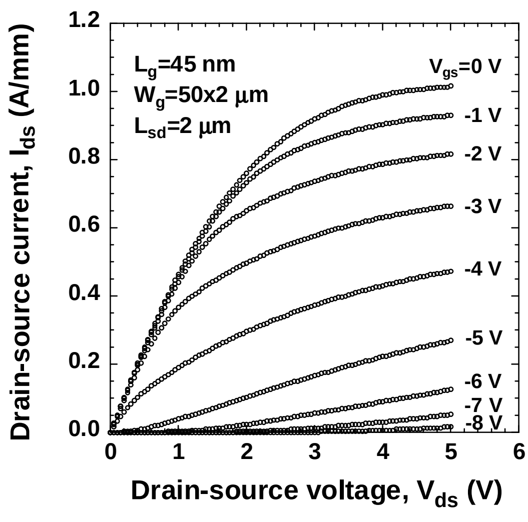

Fig. 2 Current-voltage (*I-V*) characteristics of the 45-nm-gate MIS-HEMT.

pinched off. The maximum transconductance g_{m_max} was 215 mS/mm at a drain-source voltage V_{ds} of 5 V. The S-parameters were measured in a frequency range from 0.25 to 50 GHz in 0.25-GHz steps using an HP8510C vector network analyzer and on-wafer probes. Figure 3 shows the frequency dependence of the current gain $|h_{21}|^2$ for the 45-nm-gate HEMT under a V_{ds} of 5 V and a gate-source voltage V_{gs} of -4.3 V. Note that the parasitic capacitance due to the probing pads was subtracted from the measured S-parameters. We obtained a cutoff frequency f_T of 139 GHz by extrapolating $|h_{21}|^2$ at -20 dB/decade. Recently, an f_T of 152 GHz was reported for an AlGaN/GaN MIS-HEMT grown by plasma-assisted molecular beam epitaxy (PAMBE) [4]. The f_T obtained in this work is the highest value for AlGaN/GaN HEMTs grown by MOCVD.

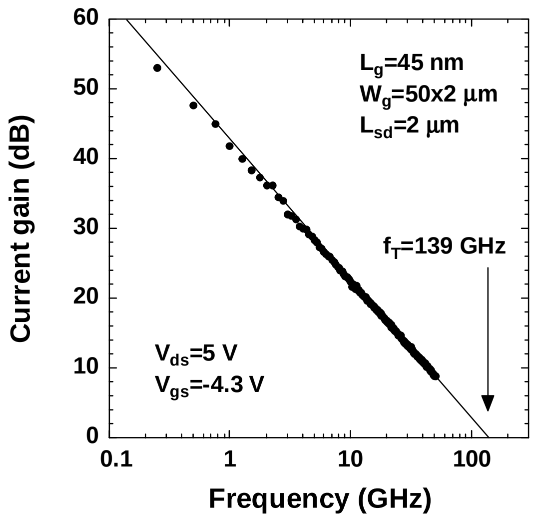

Fig. 3 Frequency dependence of current gain $|h_{21}|^2$ for the 45-nm-gate MIS-HEMT.

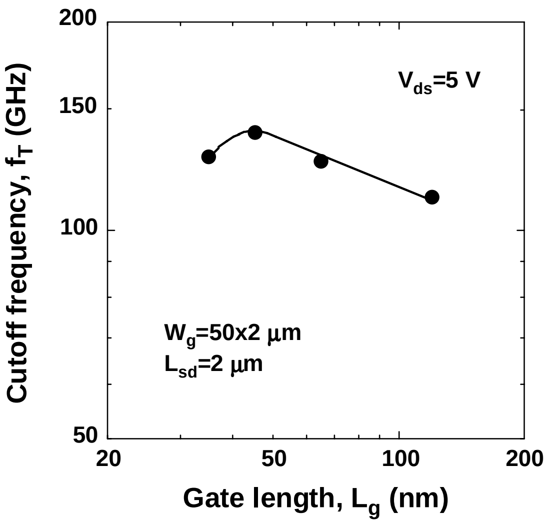

Fig. 4 Gate length L_g dependence of cutoff frequency f_T.

Figure 4 shows the L_g dependence of the f_T. The f_T increases with reducing L_g, and starts to decrease at an L_g of 35 nm. The decrease at L_g=35 nm may result from short-channel effects [5]. The f_T's obtained in this work are 30 to 40 % higher than those for the non-MIS-HEMTs with an AlGaN layer thickness of 27 nm and an R_{sheet} of 470 Ω/square in our previous work [1]. To clarify the origin of the increased f_T, we performed a transit time analysis [6]. The total delay time τ_{total} of the HEMT is expressed as $\tau_{total}=1/2\pi f_T=\tau_{transit}+\tau_p+\tau_{cc}$, where $\tau_{transit}$ is the transit, τ_p is the parasitic delay and τ_{cc} is the channel charging time. The $\tau_{transit}$ is given by $\tau_{transit}=(L_g+\Delta L)/v_{ave}$, where ΔL is the extended gate length and v_{ave} is the average velocity under the gate. The τ_p is given by $\tau_p=C_{gd}(R_s+R_d)$, where C_{gd} is the gate-drain capacitance and $R_s(R_d)$ is the source (drain) resistance. We obtained $\tau_{transit}$=0.9 ps, τ_p=0.2 ps and τ_{cc}=0.4 ps for the 120-nm-gate MIS-HEMT in this work, as against $\tau_{transit}$=1.4 ps, τ_p=0.4 ps and τ_{cc}=0.2 ps for the 120-nm-gate HEMT in our previous work [1]. Thus, a reduced $\tau_{transit}$ plays a major role in increasing the f_T's in this work. The reduction in $\tau_{transit}$ may result mainly from the increased electron velocity, since a high electric field region might have been formed at the drain-side end of the gate by the SiN passivation.

4. Summary

In summary, we proposed and fabricated AlGaN/GaN MIS-HEMTs using $SiN/SiO_2/SiN$ triple-layer insulators. The proposed MIS-HEMTs are mechanically stable in the sub-50-nm-gate region and free from damage by the dry etching process. We obtained an f_T of 139 GHz for the 45-nm-gate HEMT. This f_T is the highest value for AlGaN/GaN HEMTs grown by MOCVD.

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