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Low Current Collapsed AlGaN/GaN HEMT-on-Si Substrate with SiN_x / HfO_2 Dual Passivation Layer

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Abstract

The current collapse phenomena of AlGaN/GaN HEMTs-on-Si substrates were effectively suppressed by employing SiN_x/HfO_2 dual passivation layer. In this experiment, HfO_2 layer using ALD (atomic layer deposition) was deposited on SiN_x passivation layer with different ratio of SiN_x/HfO_2. To evaluate each performance of the fabricated devices, we measured pulsed I-V and DC characteristics. The current collapse phenomena were reduced and threshold voltages were positively shifted as the thickness of HfO_2 layer increased.

1. Introduction

GaN based HEMTs have played an important role in microwave power and high power switching applications due to their excellent characteristics, such as a wide bandgap, high breakdown field, and high saturation velocity.

However, there are some remained technical issue caused from material quality especially Gan-on-Si. Current collapse which is one of the main parts of GaN research can be suppressed by good dielectric passivation, field-plate, and surface treatments. A SiN_x layer is a good dielectric for GaN device passivation, but it is not general to achieve low current collapse characteristic by using few nm thickness [1] because of some reasons. A Thick passivation layer for better current collapse performance may cause degradation of RF parameters in microwave applications of GaN devices.

In this work, we proposed the structure of dual passivation layer with high-k dielectric only with thickness of 60 nm totally on AlGaN/GaN HEMTs-on-Si substrates that can help to make reliable devices and better characteristics with reduced trapping effects from the front processes.

2. Device Fabrication and Discussion

Process and device split

The epitaxial layers were grown on Si substrate consisted of a 2.5 nm GaN capping layer, a 20 nm Al0.26Ga0.74N barrier layer, a 800 nm undoped GaN buffer layer, and 1.4 μm C-doped GaN buffer layer. The material showed carrier mobility of ~1600 cm^2/Vs.

After surface cleaning, 100 nm SiN_x film was pre-deposited using inductively coupled plasma chemical vapor deposition (ICP-CVD) in order to protect the GaN surface during high temperature annealing [2]. Ohmic contacts with L_{SD} = 18 μm were performed with low damage recess etching using BCl_3/Cl_2 plasma and Si/Ti/Al/Mo/Au (5/20/80/35/50 nm) at 800 °C in N_2 ambient. Mesa isolation was carried out by BCl_3/Cl_2 plasma etching again only with different power. The transfer contact resistance was 0.69 Ω·mm and the sheet resistance was 440 Ω/sq. In order to improve the interface condition between the passivation film and GaN surface, the pre-passivated SiN_x film was removed by low damage SF_6 plasma etching [3] and a fresh 60 nm SiN_x film was subsequently re-deposited using Cat-CVD (Catalytic-CVD) which can remove plasma damage on the GaN surface. For the comparison, two more pieces of samples were fabricated with same process flow. As shown in the Fig. 1 (b), SiN_x/HfO_2 (50/10 nm) and SiN_x/HfO_2 (40/20 nm) dual passivation layers were deposited on each sample. HfO_2 layer was deposited at 360 °C chuck in ALD chamber using ozone. Finally, 2 μm gates were defined and etched by CF_4/O_2 two-step plasma etching, and Ni/Au (40/160 nm) metals were deposited. First step of high power CF_4/O_2 plasma was used to etch HfO_2 layer effectively.

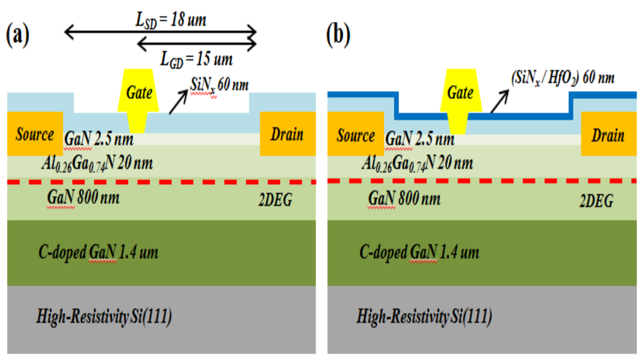

Fig. 1 Structures of fabricated devices (a) using only SiN_x passivation layer and (b) using SiN_x / HfO_2 dual passivation layer.

Results and discussion

We measured DC performances of the devices, and maximum transconductances were 150 mS/mm for all, but threshold voltages were positively shifted as HfO_2 ratio were increased, showed in Fig. 2. The breakdown measurements were estimated by gate reverse leakage current and drain off-state leakage current, and there were no remarkable differences among each device (Fig. 3).

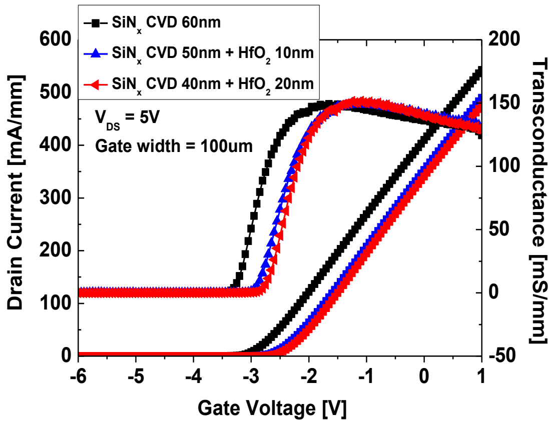

Fig. 2 Transfer characteristics of fabricated devices with different passivation layers at V_{DS} = 5V.

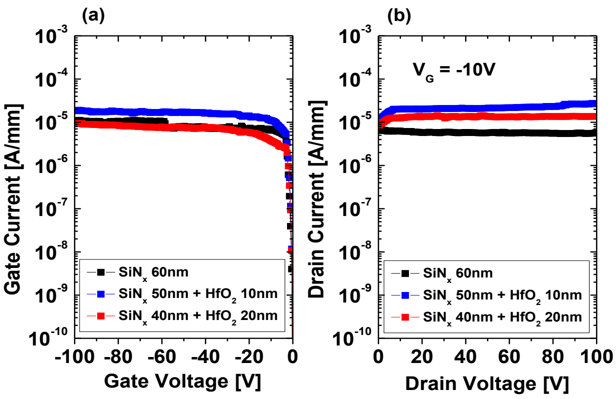

Fig. 3 (a) Gate reverse leakage currents and (b) Drain off-state leakage currents of the devices with three different passivation layers (gate width = 100 μm).

However, pulsed I-V characteristics which indicate current collapse phenomenon were significantly improved as thickness of HfO_2 was increased as shown in the Fig. 4. The current collapse was measured only about 14% at $V_{GS,Q}$ = -5 V, $V_{DS,Q}$ = 50 V at the device with SiN_x 40 nm and HfO_2 20 nm dual passivation layer.

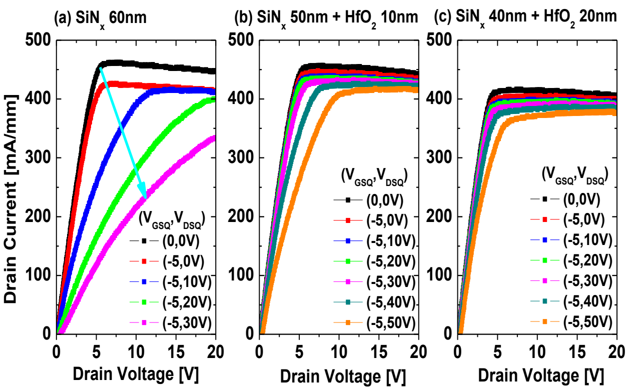

Fig. 4 Pulsed I-V characteristics of fabricated devices with different passivation layers (gate width = 2 x 50 μm). Measurements for 500 ns pulse duration at V_{GS} = 0 V.

The effects of dielectric constants of passivation layers on breakdown voltage have been researched by simulation that high-k properties are better for reducing electrical field near the gate edge [4], and the improvement of microwave power characteristics using HfO_2 and TiO_2 for passivation layers were exhibited [5]. But, there are not exact studies about the effects of HfO_2 on current collapse phenomenon. Although further investigation is needed, this result can suggest reliable process technique to easily suppress current collapse which is the main technical issue for GaN devices, also showed great potential for applying to microwave devices to achieve low current collapse with only few nm passivation layers. To prevent degradation of RF parameters from increase of HfO_2 thickness while the thickness of SiN_x is reduced, quality of HfO_2 and optimum ratio of dual passivation layer between improvement of current collapse phenomenon and increase of parasitic capacitances should be researched further.

3. Conclusions

We demonstrated AlGaN/GaN HEMT-on-Si substrate with low current collapse phenomenon which is important for microwave power devices by employing SiN_x/HfO_2 (40/20 nm) dual passivation layer with total thickness of 60 nm. Thick passivation layer contributes to not only suppression of current collapse but also poor frequency response. This experiment proved the great potential of improving device performance without increase of passivation thickness, and better result from more optimization of thickness ratio can be applied for GaN-on-Si high frequency applications.

Acknowledgements

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