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Improvement in Performance of AlGaN/GaN HFETs by Utilizing a Low-Temperature GaN Cap Layer

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1. Introduction

AlGaN/GaN heterostructure field-effect transistors (HFETs) have emerged as highly attractive candidates for high-power, high-frequency, and high-temperature. Even though much progress has been made in improving the high-frequency performance of HFETs, some remaining problems such as high gate leakage current and current collapse must be solved.

It is known that low-temperature (LT) GaN exhibits ultrahigh resistivity that cannot be reduced even by thermal annealing [1]. However, it has recently been shown that utilizing a LT-GaN layer increases the Schottky barrier height in GaN-based metal-semiconductor-metal (MSM) photodiodes (PDs), so the leakage current can be reduced [2]. Given these beneficial properties, LT-GaN may be a suitable gate insulator and provide surface passivation for AlGaN/GaN HFETs. In the present study, AlGaN/GaN HFETs were fabricated by depositing a LT-GaN cap layer on an AlGaN barrier layer. The electrical properties of the fabricated HFETs were investigated, and the effects of the cap layer on the key problems of current collapse and gate leakage were determined.

2. Device Structure and Fabrication

AlGaN/GaN layers were grown by metal-organic chemical vapor deposition (MOVCD) under atmospheric pressure on (0001)-oriented sapphire substrates. Figure 1 shows the schematic diagram of epitaxial layers and cross-sections of the fabricated AlGaN/GaN HFET. First, a 30-nm-thick GaN nucleation layer was grown on the substrate at 550°C, followed by a 2.5-μm-thick undoped GaN layer deposited at 1080°C. The heterostructure was capped by depositing a 7-nm-thick $Al_{0.26}Ga_{0.74}N$ spacer layer, a 15-nm-thick Si-doped $Al_{0.26}Ga_{0.74}N$ charge supply layer with a doping level of $4x10^{18}/cm^3$, and a 3-nm-thick $Al_{0.26}Ga_{0.74}N$ barrier layer. These AlGaN layers were grown at 1080°C. Finally, a 10-nm-thick LT-GaN cap layer was deposited at 550°C on the AlGaN barrier layer.

Ti/Al/Ti/Au (10/200/50/300 nm) metallization layers were then evaporated to provide source and drain ohmic contacts. The contacts were annealed under a nitrogen atmosphere at 800°C for 30s. Ni/Au (20/530 nm) metallization layers were then used to form gate Schottky contacts. Device isolation was achieved by applying a mesa etch with Ar ion milling. The devices were fabricated with a source-drain spacing of 10 μm, a gate length of 2 μm and a gate width of 100 μm. They were not passivated. For comparison, conventional AlGaN/GaN HFETs were also fabricated, with a heterostructure identical to that described above except for the LT-GaN cap layer. To investigate the properties of the Schottky barrier, Schottky diodes with a contact area of 100 μm x 100 μm were fabricated with the same epitaxial wafers.

3. Results and Discussion

The current-voltage (I-V) characteristics of the fabricated Schottky diodes were measured with an HP4156 semiconductor parameter analyzer, and the results are shown in Fig. 2. We found that under reverse bias the leakage current for the Schottky diodes with the LT-GaN cap layer was at least two orders lower than that for the conventional Schottky diodes. Under forward bias, the turn-on voltage of the diodes with the LT-GaN cap layer was higher than that of the conventional diodes. The lower leakage current and higher turn-on voltage could be attributed to the fact that the semi-insulating LT-GaN cap layer enabled a higher Schottky barrier height.

Figure 3 shows typical transfer characteristics for the fabricated HFETs, as measured with the HP4156. Maximum transconductances of 95 and 90 mS/mm were measured for the HFETs with and without a LT-GaN cap layer, respectively. As shown in Fig. 3, the HFETs with the cap layer exhibited a larger gate voltage swing up to +3 V with higher linearity, as compared to the conventional HFETs.

We also studied the effect of the LT-GaN cap layer on current collapse in the fabricated HFETs. For this purpose, we measured the I-V characteristics under pulse-mode gate stress by using a Sony Tektronix 370A, with various drain sweeping voltages (V_{ds}): 0-10 V, 0-20 V, and 0-40 V. The pulse width and duty cycle used in this experiment for V_g pulses were 300 μsec and 3%, respectively. The baseline of the V_g pulses was set to –4 V, which was below the V_{th} of the HFETs.

Figure 4 shows the pulse-mode I-V characteristics for HFETs with and without a LT-GaN cap layer. As shown in Fig. 4(a), the knee voltage became larger with increasing V_{ds} for the HFETs without the cap layer. This clearly indicated gate-stress-induced current collapse [3]. On the other hand, no significant current collapse was observed for the HFETs with the LT-GaN cap layer, indicating its remarkable benefits as a gate insulator and surface passivation layer. One possible mechanism by which the

LT-GaN cap layer prevents current collapse is that it may suppress electron injection from the gate to the surface states, in a manner similar to the effect of SiN surface passivation [4]. Another possible mechanism is that the cap layer may eliminate the surface states due to the LT-GaN surface passivation process. Further study is required to establish the exact mechanism.

4. Conclusion

We applied a LT-GaN cap layer serving as a gate insulator and providing surface passivation to AlGaN/GaN HFETs. We found that this approach could significantly reduce the leakage current and achieve a high turn-on voltage for Schottky barrier diodes. HFETs with the LT-GaN layer showed a larger gate voltage swing up to Vg = +3 V with higher linearity, as compared to conventional HFETs. Moreover, no current collapse was observed in the novel HFETs under pulse-mode gate stress. The results demonstrate that the application of a LT-GaN cap layer to serve as a gate insulator and to provide surface passivation is a promising technique for improving the surface stability of AlGaN/GaN HFETs.

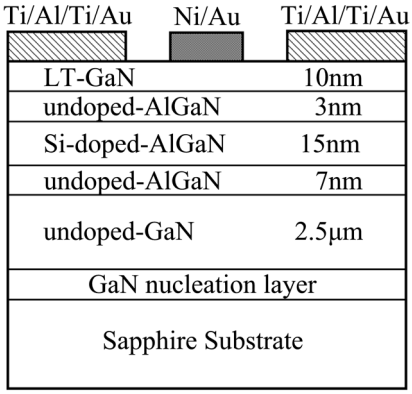

Fig. 1. Schematic diagram of epitaxial layers and cross-sections of a fabricated AlGaN-GaN HFET with a LT-GaN cap layer.

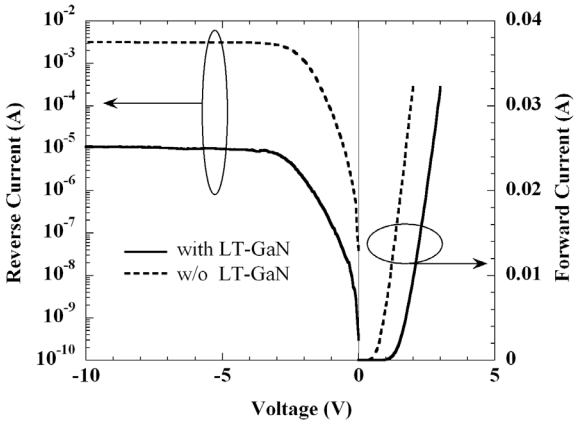

Fig. 2. I-V curves for Schottky barrier diodes with and without a LT-GaN cap layer.

References

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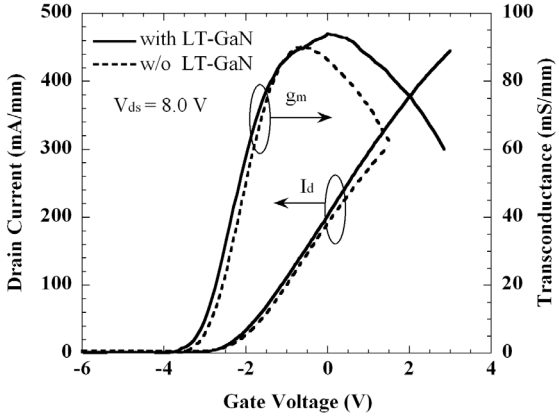
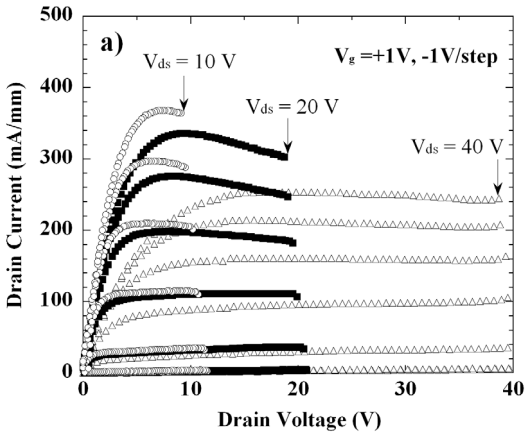


Fig. 3. Transfer characteristics of AlGaN-GaN HFETs with and without a LT-GaN cap layer. Measurement was done at a drain voltage of 8.0 V.



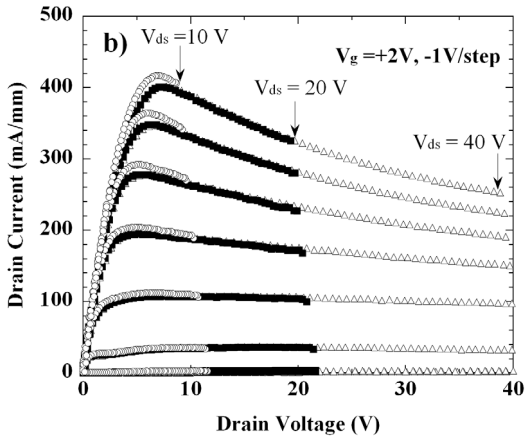


Fig. 4. Pulse–mode I-V characteristics (for V_{ds} = 10, 20, and 40 V) of AlGaN-GaN HFETs (a) without a LT-GaN cap layer and (b) with a LT-GaN cap layer.