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Effect of multiple carbon-doped/undoped GaN buffer layer on current collapse in AlGaN/GaN HEMTs

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Abstract

The current collapse in AlGaN/GaN HEMTs with different buffer structures has been investigated. The HEMT with carbon-doped GaN buffer layer exhibited much suppressed current collapse than that of HEMT with unintentionally doped high resistive GaN buffer because the carbon plays a role of compensating the native defects such as dislocations acting as deep traps. The collapse in HEMT with proposed buffer structure consisting of carbon-doped (C-GaN)/undoped (u-GaN) multiple-layers (MLs) was further suppressed. This possibly explains that the growth of ML layer effectively reduces the dislocation density in the buffer layer because the growth temperature correspondingly changed during the growth of each layer.

1. Introduction

AlGaN/GaN HEMTs have received much attention for high-power and high-frequency device applications because of their material advantages. However, the conductive nature of GaN material owing to inevitably introduced background *n* doping during the growth would limit the device performance. Therefore, semi-insulating (S.I.) GaN buffer layer is required to minimize the off-state leakage current and to avoid parallel conduction. The S.I. GaN buffer layer is successfully grown by incorporating deep impurities such as iron (Fe) or carbon (C) atoms into the GaN layer or introducing high density of threading dislocations and/or other defects during the growth, which compensated the donor states like oxygen or nitrogen vacancy [1,2].

The current collapse phenomenon in AlGaN/GaN HEMTs is mainly due to the electron trapping into the bulk traps in the GaN buffer layer at high drain voltage which is responsible for the drain lag. It was, recently, reported that the drain lag in AlGaN/GaN HEMTs is attributed to bulk traps such as high dislocation densities and/or deep acceptor states in the S.I. GaN buffer layer [3,4]. It is known that the C-doped buffer structure suppresses the current collapse in AlGaN/GaN HEMT than that in HEMT with undoped GaN buffer.

In this work, we have proposed the GaN buffer structure consisting of C-GaN/u-GaN MLs instead of the conventional thick C-doped GaN buffer layer, which is very effective in reducing the current collapse phenomenon.

2. Experiments

The AlGaN/GaN heterostructure with different buffer structures (sample A, B, and C) were grown to investigate the effect of buffer structure on current collapse, as shown in Fig. 1. The buffer structure of sample A was a 2 μm-thick unintentionally doped S.I. GaN (UID S.I. GaN) layer high dislocation densities generated during growing. The buffer structure of sample B was a 1 μm-thick C-GaN on 2 μm-thick UID S.I. GaN layer and sample C was thin C-GaN (12 nm)/u-GaN (50 nm) MLs with total thickness of 2 μm. For fabrication of HEMT, MESA etching was performed by using ICP-RIE for the device isolation. Ohmic metal stacks of Si/Ti/Al/Ni/Au (1/25/160/40/100 nm) were deposited with traditional lift-off technique and annealed in N_2 ambient. Subsequently, Ni/Au (40/50 nm) was formed as Schottky gate contacts utilizing electron beam evaporator. In order to prevent the gate lag effect on devices, AlGaN surface was passivated by a 70 nm-thick SiO_2 layer. The defined gate length and width of fabricated devices were 3 and 50 μm, respectively.

3. Results and discussion

The buffer leakage currents of the samples, as shown Fig. 2, were measured by using mesa-to-mesa pattern with a distance of 20 μm. HEMTs with UID S.I. GaN buffer and C-GaN buffer showed extremely low buffer leakage current, which indicates all buffer structures were semi-insulating nature. The buffer leakage current of C-doped GaN buffer layer was slightly lower than that of UID S.I. GaN buffer layer due to incorporation of carbon atoms, which acts as deep acceptor and become more resistive. However, the sample A suffers from severe current collapse from 354 to 192 mA/mm when the sweeping drain voltage increases to 100 V as shown Fig. 3 (a). The severe current collapse is because the electron trapping into the bulk traps near drain at high drain voltage acts as negative charge state which not only decreases the electron density of the channel layer, but also increases electron scattering and hence decreases the electron mobility in the channel. On the other hand, the device with the C-GaN buffer layer (sample B) exhibits the suppressed current collapse when the sweeping drain voltage increases to 50 V. These results suggest that carbon plays a role of compensating the native defects such as dislocations. However, the current collapse still occurs at high drain bias of 100 V in sample B due to the high density of traps in UID S.I.GaN buffer layer under the C-GaN buffer layer. The drastic reduction of the current collapse is observed in the proposed structure (sample C), as shown Fig. 3(c). The proposed buffer structure consisting of C-GaN/u-GaN MLs is much more effective in suppressing the current collapse even at high drain voltage. This possibly explains that the growth of ML layer effectively reduces the dislocation density in the buffer layer because the growth temperature correspondingly changed during the growth of each layer.

4. Conclusions

The current collapse in AlGaN/GaN HEMTs was investigated by using the new GaN buffer structure consisting of C-GaN/u-GaN MLs. A serious current collapse was observed in HEMT with UID S. I. GaN buffer. The current collapse was drastically suppressed in HEMT using C-GaN buffer structure because the carbon plays a role of compensating the native defects. GaN HEMT with the C-GaN/u-GaN MLs buffer structure was much more effective to suppress the current collapse due to the reduction of dislocation density in the buffer layer.

Acknowledgements

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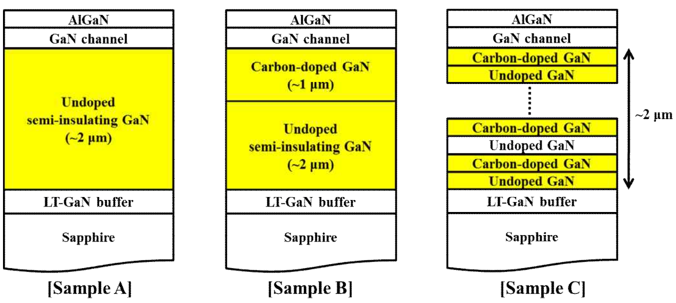

Fig. 1 Schematic cross-sectional view of AlGaN/GaN epi structures (a) UID S.I. GaN buffer, (b) C-doped GaN buffer, (c) C-GaN/u-GaN MLs buffer.

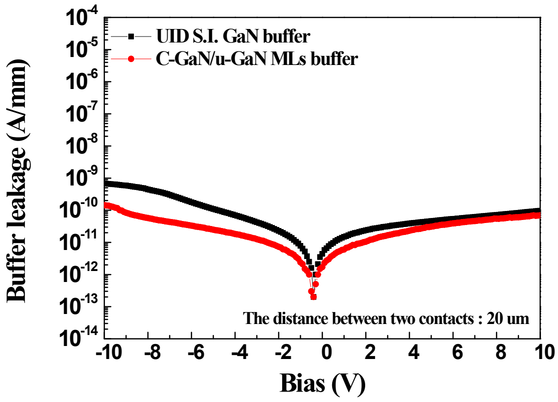

Fig. 2 Buffer leakage characteristics of various GaN buffer structures

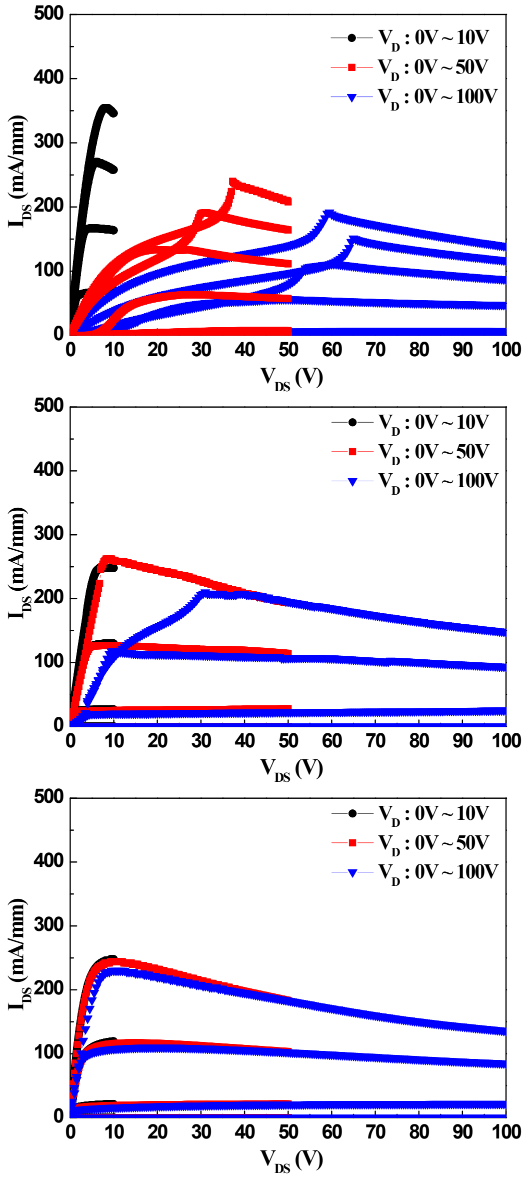

Fig. 3 I_D-V_D characteristics of GaN HEMTs with different buffet structure (a) UID S.I. GaN buffer, (b) C-doped GaN buffer, (c) C-GaN/u-GaN MLs buffer.