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Suppression of off-state drain leakage current in AlGaN channel high electron mobility transistors on SiC substrate

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1. Introduction

AlGaN has a higher electric breakdown field than that of GaN and GaAs because of a wider bandgap in AlGaN than in GaN and GaAs. Therefore, employing AlGaN for the channel layer of high electron mobility transistors (HEMTs) is an attractive method to enhance breakdown voltage compared to conventional GaN-based or GaAs-based HEMTs. By the enhancement of breakdown voltage, higher power operations are expected in high-frequency devices and high-power switching devices. We, for the first time, realized an operation of HEMTs with AlGaN channel layer (AlGaN channel HEMTs) by applying Si ion implantation doping techniques for source/drain electrodes to improve high-resistance ohmic contacts due to wider bandgap of AlGaN[1]. We have also demonstrated extremely high off-state breakdown voltages[2] and competitive drain current densities[3] in AlGaN channel HEMTs compared to conventional GaN channel HEMTs. However, in AlGaN channel HEMTs on SiC substrate, relatively large off-state drain leakage current flowed and this drain leakage current deteriorated the off-state breakdown voltage[4].

In order to suppress such drain leakage current in conventional GaN channel HEMTs, carbon doping in the deep region of channel layer (C-doped structure) is used because the doped carbon can compensate for unintentionally doped n-type impurities. Double-hetero (DH) structure is also used to suppress the drain leakage current because AlGaN back-barrier layer could deplete in the deep region of the channel and buffer layer. In this paper, C-doped structure and DH structure are employed in AlGaN channel HEMTs to suppress the off-state drain leakage current. Off-state drain leakage currents were fully suppressed in fabricated AlGaN channel HEMTs on SiC substrate.

2. Experimental

Figure 1 shows the cross-sectional structure of the fabricated AlGaN channel HEMTs on SI-SiC substrates. In this study, we investigated three kinds of structures: referenced AlGaN channel structure, C-doped structure and DH structure as shown in Table I. These structures consisted of a buffer layer, a back barrier layer, a channel layer and a barrier layer. In C-doped structure, carbon was doped in the back barrier layer. In DH structure, the back barrier layer consists of higher Al composition AlGaN than in the channel layer. In all structures, the channel layer and the barrier layer consist of unintentionally doped AlGaN. In the referenced AlGaN channel structure, the back barrier layer also consists of unintentionally doped AlGaN. In all structures, Al compositions in barrier layers and back barrier layers were 0.40 and 0.15, respectively. In the referenced AlGaN channel structure and C-doped structure, Al compositions in the channel layer were the same as in the back barrier layer. Al composition in the channel layer in DH structure was 0.10. All epitaxial layers were grown on a SI-SiC substrate by a metalorganic chemical vapor deposition technique.

The fabrication process started with the formation of alloyed Ti/Al source/drain electrodes on Si ion implanted high concentrated n^+ regions. Then, device isolation was performed by Zn ion implantation and a Ni/Au Schottky gate contact was formed. The fabrication was completed by depositing SiN_x dielectric film using catalytic chemical vapor deposition and subsequent formation of Ni/Au field plates which were connected to the gate contacts at electrode pads. The gate length, the gate width, the distance between the source and gate, and the distance between the gate and drain were 1, 100, 1, and 2 μm, respectively.

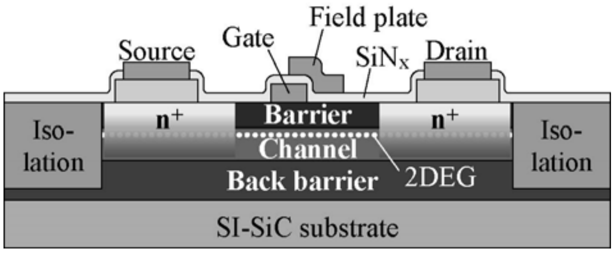

Fig.1 Schematic structure of fabricated HEMTs

Table I Epitaxial layer structures using HEMTs

		Reference	C-doped	DH
Barrier	Al composition	0.40	0.40	0.40
	Thickness	25	25	25
Channel	Al composition	0.15	0.15	0.10
	Thickness	200	200	200
Back barrier	Al composition	0.15	0.15	0.15
	Dopant	-	C	C

2. Results and discussion

Figure 2 shows drain current-drain voltage curves in the fabricated AlGaN channel HEMTs. Similar characteristics were obtained in referenced and C-doped AlGaN channel HEMTs. Drain current density in the DH AlGaN channel HEMTs was larger than that in the other two HEMTs because sheet carrier density in the DH structure was higher than that in the other two structures due to a large difference of Al composition between barrier and channel layers. In all HEMTs good pinch-off characteristics were confirmed in the linear vertical axis as shown in Figure 2.

In the referenced AlGaN channel HEMT, however, good pinch-off characteristics were not confirmed in the logarithmic axis as shown in Figure 3(a) representing drain current-gate voltage curves. On the other hand, good pinch-off characteristics were obtained in the other two HEMTs, even in the logarithmic axis as shown in Figures 3(b) and (c). These improvements were attributed to the compensation of unintentionally doped impurities by carbon doping and depletion of the deep channel region by DH structure.

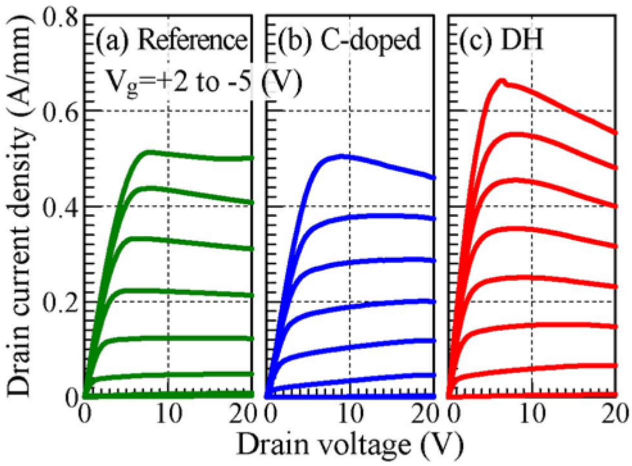

Fig.2 Drain current-drain voltage curves in the fabricated AlGaN channel HEMTs.

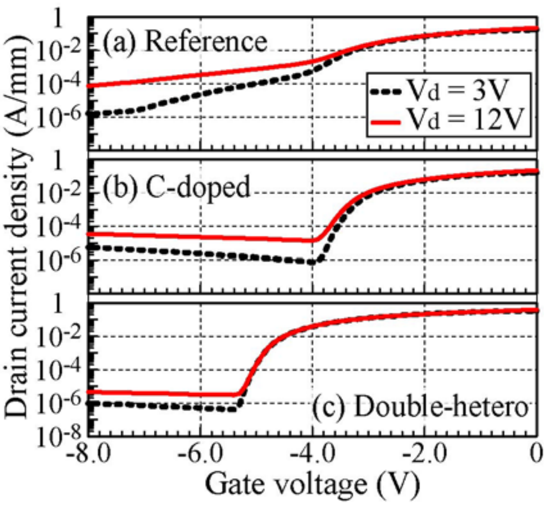

Fig.3 Drain current-gate voltage curves in the fabricated AlGaN channel HEMTs.

Figure 4 shows off-state drain voltage dependences of drain and gate current in the fabricated AlGaN channel HEMTs. We confirmed that the off-state large drain currents were sufficiently suppressed in the C-doped and DH AlGaN channel HEMTs, even in high drain voltage regions.

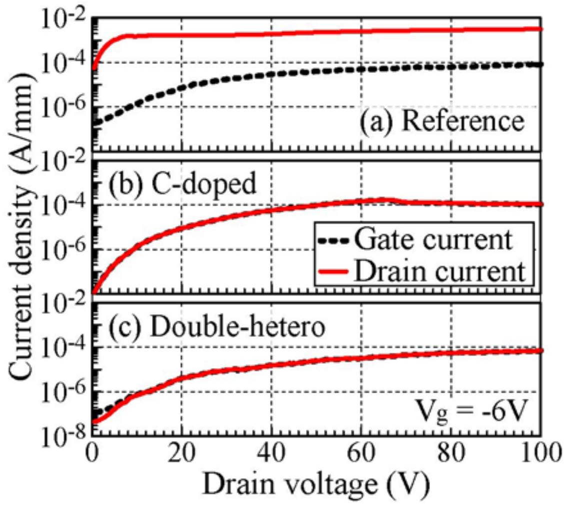

Fig.4 Off-state drain voltage dependences of drain and gate current in the fabricated AlGaN channel HEMTs.

4. Conclusions

We investigated effects of C-doping in the deep channel layer region and DH structure to suppress the off-state drain leakage current in AlGaN channel HEMTs on SiC substrate. In both structures, good pinch-off characteristics were obtained and we confirmed that these are effective to decrease drain leakage current.

Acknowledgment

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References

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