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Improved Current Collapse Phenomenon in AlGaN/GaN-on-Si HFETs Using Sacrificial GaO_x Process

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Abstract

We have developed a novel passivation process employing a sacrificial GaO_x process to suppress the current collapse phenomenon in AlGaN/GaN HFETs. Even with a conventional prepassivation process, surface damage during high temperature ohmic annealing cannot be avoided completely, which in turn induces surface trapping states. In this proposed process, the damaged surface after high temperature ohmic annealing was removed by a sacrificial GaO_x process prior to SiO_2 surface passivation. As a result, surface damage induced trapping effects were successfully suppressed.

1. Introduction

AlGaN/GaN heterostructure field effect transistors (HFETs) are very suitable for high frequency power and power switching applications. One of the important issues in RF and switching characteristics of AlGaN/GaN HFETs is the current collapse phenomenon associated with surface trapping effects. Thus, surface passivation using various types of dielectric materials, such as SiN_x, SiO_2, Al_2O_3, AlN, etc., has been intensively studied in many research groups [1-4]. It was reported that not only poor surface/interface conditions between AlGaN/GaN and passivation layer but also surface damage associated with high temperature ohmic annealing was responsible for trapping phenomenon. Several studies reported that appropriate plasma treatments reduced the interface states [5, 6] and a prepassivation process was effective to protect the surface during ohmic annealing [1]. In this study, we proposed a new process employing a sacrificial GaO_x layer and SiO_2 passivation to suppress the current collapse phenomenon in AlGaN/GaN HFETs.

2. Experiments

AlGaN/GaN HFETs were fabricated using three different processes, as shown in Fig. 1. Process (1) employed a conventional prepassivation process using SiO_2. In processes (2) and (3), a SiN_x prepassivation process was utilized but the protecting prepassivation layer was etched away after high temperature ohmic annealing and followed by SiO_2 passivation. In process (3), the O_2 plasma treatment was performed after etching the SiN_x prepassivation layer in order to form a GaO_x sacrificial layer at the surface that was etched back prior to SiO_2 passivation.

The epitaxial structure consisted of a 2-nm undoped GaN layer, a 30-nm $Al_{0.25}Ga_{0.75}N$ barrier, and a 100-nm GaN layer and 3.9-μm carbon-doped GaN buffer layer on a p-type Si (111) substrate. The process began with mesa isolation using a Cl_2/BCl_2-based ICP-RIE process. A 30 nm SiO_2 film was deposited as a prepassivation layer for process (1) whereas a 10 nm SiN_x film was deposited as a surface protection layer during ohmic annealing for processes (2) and (3). A Si/Ti/Al/Mo/Au (= 5/20/60/35/50 nm) was used for ohmic contacts, which were annealed at 830°C in N_2 ambient. After ohmic annealing, the SiN_x film was etched away using BOE in processes (2) and (3). A 30 nm SiO_2 film was then deposited at 250°C using ICPCVD as a passivation layer for process (2) [2]. In process (3), an additional process step was performed prior to SiO_2 deposition; O_2 plasma treatment was carried out to form a GaO_x sacrificial layer that was etched back using diluted HCl solution. It is suggested that this sacrificial layer process not only remove the damaged surface but also improve the interface quality between AlGaN/GaN and SiO_2. The gate region was patterned and etched using BOE, and an ad-

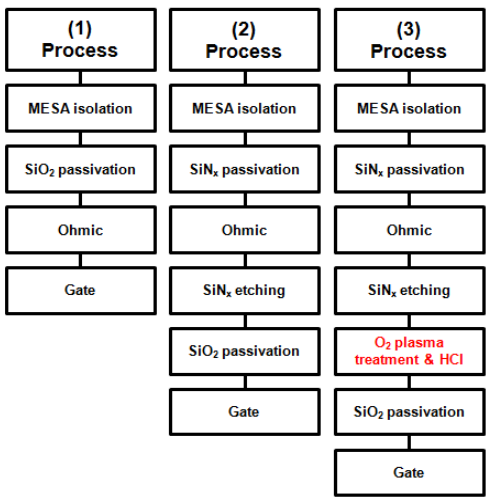

Fig. 1 Three different processes compared in this study.

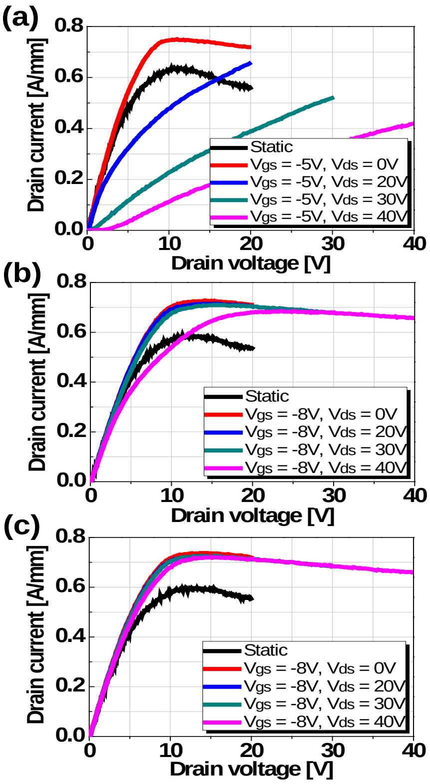

Fig. 2 Static and pulsed current-voltage characteristics of AlGaN/GaN HFETs fabricated using (a) process (1), (b) process (2), and (c) process (3). The pulsed I-V characteristics were measured using a pulse width of 0.5 μs with a period of 1 ms. The quiescent bias conditions were varied from V_{ds} = 0 V to V_{ds} = 40 V with fixing the gate bias under complete pinch-off conditions. The source-to-gate distance, gate length, and gate-to-drain distance were 3, 2, and 12 μm, respectively.

ditional lithography process defined the field plated gate. A Ni/Au stack was used for gate metallization. As a stabilization annealing process, a rapid thermal annealing was carried out at 400^{o}C for 5 min in N_2 ambient.

3. Results and discussion

Figure 2 shows the static and pulsed current-voltage characteristics of AlGaN/GaN HFETs fabricated using processes (1), (2), and (3). A significant current collapse phenomenon was observed for process (1) where the high temperature ohmic annealing was carried out with the SiO_2 protection layer. Lin *et al.* reported that Ga out-diffusion into SiO_2 produced defects and damaged the lattice structure of SiO_2 during high temperature annealing [7]. This annealing induced surface damage is responsible for the significant current collapse phenomenon. It is known that Ga atoms tend to more easily diffuse into SiO_2 compared to SiN_x [8]. Therefore, it is suggested that a SiN_x film is a better choice as a protection layer for GaN surface during high temperature annealing. In processes (2) and (3), the surface was protected by a SiN_x film during ohmic annealing and the following SiO_2 passivation layer was not exposed to high temperature annealing. As a result, the current collapse phenomenon was significantly suppressed in processes (2) and (3). Slightly better pulsed characteristics were observed for process (3) compared to process (2), especially under high quiescent drain bias conditions. It is suggested that the sacrificial GaO_x process prior to SiO_2 passivation in process (3) removed the damaged surface associated with high temperature ohmic annealing, resulting in high quality surface.

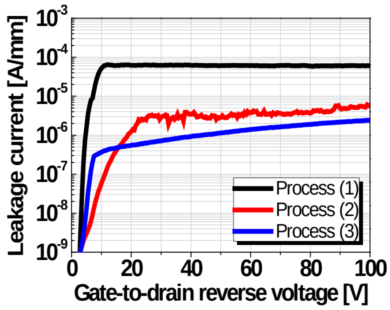

Fig. 3 Leakage characteristics in three different processes.

As shown in Fig. 3, the leakage current dramatically decreased in processes (2) and (3) in comparison with process (1). It is suggested that the SiN_x film is suitable to protect the surface during ohimc annealing and the following SiO_2 passivation in conjunction with a sacrificial GaO_x process is effective to suppress the current collapse phenomenon and reduce the leakage current.

4. Conclusions

We have developed a new process using SiN_x protection and sacrificial GaO_x. The SiN_x protection layer prevents Ga-out diffusion from GaN surface and the sacrificial GaO_x process improves the interface quality between SiO_2 and AlGaN/GaN. It is suggested that the proposed process can effectively suppress the current collapse phenomenon and reduce the leakage current in AlGaN/GaN HFETs.

Acknowledgements

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