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Increase of Breakdown Voltage in AlGaN/GaN HEMTs by Employing As+ Ion Implantation on SiO_2 Passivation Layer

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1. Introduction

AlGaN/GaN high-electron-mobility transistors (HEMTs) have attracted considerable attention because of a high breakdown field in the wide band-gap semiconductor [1, 2].

A breakdown voltage is very important in high power applications. Considerable amount of works have been reported to achieve a high breakdown voltage by employing additional processes such as SiO_2 passivation, floating metal rings and Ni/Au Oxidation [3-5]. The breakdown of AlGaN/GaN HEMTs is related with the potential distribution between the gate and the drain electrodes. Passivation layer suppresses electron trapping at surface states. Passivation layer changes the potential distribution between the gate and the drain electrodes and increases the breakdown voltage [6].

Without the passivation, electrons are trapped from the gate to the surface states when gate electrode is reverse-biased. Then the virtual gate is formed at gate-drain access region, so that the high-field region is formed at the drain edge [6, 7]. In the passivated AlGaN/GaN HEMTs, high field at the drain edge is relaxed. A potential drop occurs at the gate edge, and electric field concentration is terminated due to the suppression of the virtual gate [6].

The purpose of our work is to report an increase of breakdown voltage in AlGaN/GaN HEMTs by employing As+ ion implantation on SiO_2 passivation layer. Treatment of passivation layer has been reported scarcely. We have fabricated AlGaN/GaN with passivation layer and implanted As+ ion on the surface passivation layer of devices. After ion implantation, (As+ 80 keV 1×10^{14} atoms/cm^2) the edge termination effect was enhanced. The breakdown voltage of AlGaN/GaN HEMTs increased without any considerable decrease of forward characteristics. Before ion implantation, the breakdown voltage of AlGaN/GaN HEMTs was 432 V. After ion implantation, the breakdown voltage was increased to 952 V.

2. Device Structure and Fabrication

The cross-sectional view of the fabricated AlGaN/GaN HEMTs is shown in Fig. 1. The AlGaN/GaN heterostructure was grown on semi-insulating 4H-SiC substrate by metal organic chemical vapor deposition (MOCVD). The 270 nm mesa structure for isolation was formed by inductively coupled plasma etching. Ohmic metal of source and drain electrodes, Ti/Al/Ta/Au (15/60/20/100 nm) were formed simultaneously with an e-gun evaporator and defined by a lift-off technique and annealed at 850 °C for 30 s under N_2 ambient. Schottky metal of gate electrode Ni/Au (50/200 nm) was formed simultaneously with an e-gun evaporator and defined by a lift-off technique. The SiO_2 passivation layer (350 nm) was deposited with inductively coupled plasma chemical vapor deposition (ICP CVD). Then As+ ion was implanted on AlGaN/GaN HEMTs under various conditions, energy was 80 keV and dose was $2\sim10 \times 10^{13}$ atoms/cm^2.

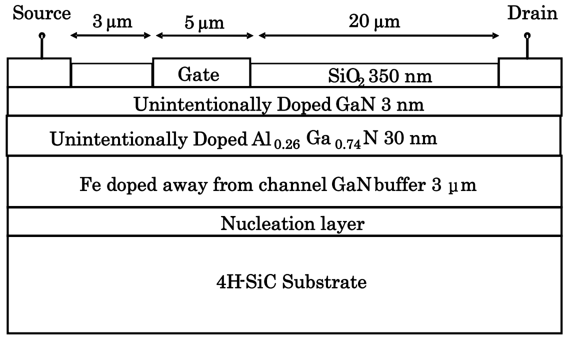

Fig. 1. Cross-sectional view of fabricated AlGaN/GaN HEMT

3. Experimental Result

After As+ ion implantation on the surface passivation layer of AlGaN/GaN HEMTs, the breakdown voltage increased due to positive charge of implanted As+ ions. Positive charge of As+ ions in the surface passivation layer contributes the electric field termination by suppressing the formation of virtual gate more effectively than as-deposited passivation layer. Table. 1 shows the increase of breakdown voltage of AlGaN/GaN HEMTs under various ion implantation conditions.

Dose (×10^{13}atoms/cm^2)	Breakdown voltage
Before	432
2	565
5	622
10	952

Table. 1. Breakdown voltage of AlGaN/GaN HEMTs with various ion implantation conditions

When the gate electrode is reverse-biased, the electrons are injected from the gate edge to the gate-drain access region. Those electrons eliminate the positive charge of donor-like surface states so that the virtual gate is formed. The virtual gate may behave like a negatively biased metal gate. The depletion edge is formed at the drain side, the electric field is concentrated near the drain edge [7]. The surface passivation prevents an electron injection from the gate to the gate-drain access region so that the potential distribution is changed and moderate field strength is formed [6]. Proposed As+ ion implantation method enhanced the supression of virtual gate due to positive charge of As+ ions.

To verify that As+ ions exists as positively charged ions in SiO_2 layer after the ion implantation, we measured the potential of As+ ion implanted SiO_2 film on Si wafer by electric force microscopy (EFM). Fig. 3 shows the EFM measurement. A bright region is a high electric potential region and a dark region is a low electric potential region, relatively. The center of SiO_2 pattern was only As+ ion implanted and left, right side of SiO_2 pattern had been screened so they were not ion implanted. The result shows that implanted As+ ions exist as positively charged ions after the ion implantation.

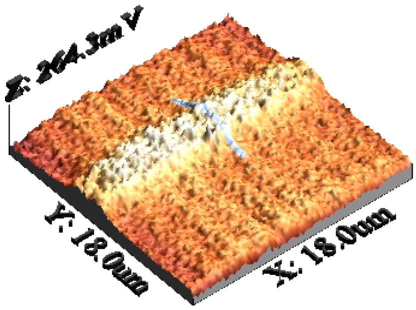

Fig. 3. Surface potential of As+ ion implanted SiO_2 film on Si wafer (EFM image)

After ion implantation, 2DEG was increased as the implanted ion increased due to the relationship between surface states and 2DEG concentration. The positive charge at the surface of AlGaN/GaN heterostructure contributes the formation of 2DEG so that 2DEG concentration of As+ ion implanted AlGaN/GaN HEMTs was increased. Table. 1 shows the result of Hall measurement. As 2DEG concentration was increased, electron mobility was decreased due to electron scattering.

Dose ($\times 10^{13}$atoms/cm^2)	Mobility (cm^2/Vs)	2DEG Concentration (/cm^2)
Before	1690	7.29×10^{12}
2	1620	7.48×10^{12}
5	1550	8.01×10^{12}
10	1360	8.92×10^{12}

Table. 1. The results of Hall measurement according to ion implanted As+ dose

Due to the increase of 2DEG concentration of AlGaN/GaN HEMTs, forward characteristics were less degraded. Fig. 4 and Fig. 5 shows that the transconductance and I-V curve of the proposed device was less degraded.

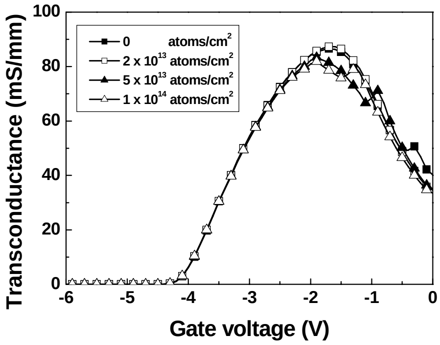

Fig. 4. Transconductance of AlGaN/GaN HEMTs with various ion implantation conditions

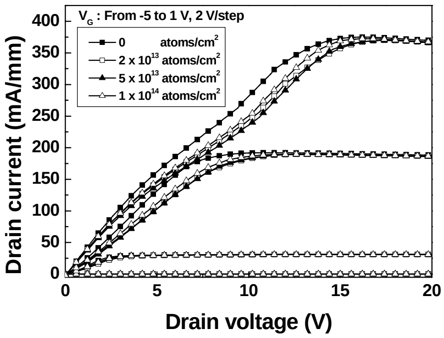

Fig. 5. I-V curves of AlGaN/GaN HEMTs at various ion implantation conditions

4. Conclusion

We have fabricated SiO_2 passivated AlGaN/GaN HEMTs and employed As+ ion implantation on the passivation layer. As+ ion implantation increased breakdown voltage of AlGaN/GaN HEMTs from 432 to 952 V without any considerable decrease of forward characteristics. As+ ion implantation successfully contributed to change the potential distribution of 2DEG region by suppressing electron injection from gate to gate-drain access region. As+ ion implantation is a very simple and effective edge termination method.

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