The Field Modulation Effect of a Fluoride Plasma Treatment on the Blocking Characteristics of AlGaN/GaN High Electron Mobility Transistors

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We designed and fabricated aluminium gallium nitride (AlGaN)/GaN high electron mobility transistors (HEMTs) with stable reverse blocking characteristics established by employing a selective fluoride plasma treatment on the drain-side gate edge region where the electric field is concentrated. Implanted fluoride ions caused a depolarization in the AlGaN layer and introduced an extra depletion region. The overall contour of the depletion region was expanded along the drift region. The expanded depletion region distributed the field more uniformly and reduced the field intensity peak. Through this field modulation, the leakage current was reduced to 9.3 nA and the breakdown voltage \(V_{BR}\) improved from 900 V to 1,400 V.

Keywords: Gallium nitride, Aluminium gallium nitride, High electron mobility transistor, Breakdown, Fluoride

1. INTRODUCTION

Aluminium gallium nitride (AlGaN)/GaN high electron mobility transistors (HEMTs) are a promising candidate for high power and high frequency applications due to their superior material properties [1,2]. Leakage current and premature breakdown not only degrade the blocking capabilities of power devices but also cause power losses in the system [3]. The active region leakage current is attributed to the electrons injected through the rectifying contact. In a lateral power device, the electron injection is mainly due to the strong electric field concentrated in the depletion region under the gate electrode compared to other factors [4]. In order to achieve stable blocking characteristics, such as low leakage current and high breakdown voltage, the peak intensity of the electric field at the gate depletion needs to be reduced. Our work concentrated on an investigation into the field modulation effect caused by implanted fluoride ions as well as the influence of the modified internal field on the blocking characteristics of an AlGaN/GaN HEMT. An improved blocking capability was confirmed by the measured leakage current and the breakdown voltage of the fabricated device.

2. DEVICE STRUCTURE AND FABRICATION

AlGaN/GaN heterostructure was grown on SiC substrates using metal organic chemical vapor deposition. A 30 nm-thick unintentionally doped Al\(_0.3\)Ga\(_{0.7}\)N and n 3 μm-thick GaN buffer formed the two dimensional electron gas (2DEG) channel of the AlGaN/GaN HEMT. An undoped GaN capping layer was then grown. A mesa structure with the thickness of 140 nm was formed for device isolation using the inductively coupled plasma
reactive ion etching (RIE) apparatus. In order to create the source and drain electrodes, a Ti/Al/Ni/Au (20/80/20/100 nm) based ohmic contact was e-gun evaporated then annealed at 870°C for 30 seconds under N₂ ambient. A Ni/Au (30/150 nm) based Schottky contact was also e-gun evaporated. The standard lift off method was used to define these metallization patterns. Cross-sectional view of the fabricated device was shown in Fig. 1. The device was then annealed at 500°C for 5 minutes under O₂ and N₂ ambient. A selective fluoride plasma treatment using a capacitive coupled plasma RIE apparatus was performed on the drain-side gate edge region with selected radio frequency (RF) power conditions (from 15 to 60 W) for 120 seconds. The flow rate of the CF₄ gas was set to 20 sccm at a pressure of 50 mT. The plasma treatment condition used for the device fabrication was greatly attenuated in order to minimize the surface damage. Through auger electron spectroscopy (AES) measurement, it was confirmed that fluoride atoms were implanted into the AlGaN layer.

3. RESULTS AND DISCUSSION

Fluoride atoms were implanted into AlGaN barrier layer through soft etching. The depth of the fluoride atoms was controlled by the plasma power to not invade the channel. As shown in Fig. 2, the fluoride atoms were distributed to within 5 nm from the AlGaN surface, considering the profiling time of the AES measurement. Most of these atoms were detected at the surface and buffer layer. A series of vertically expanded depletion regions was formed along the drift region by the fluoride plasma treatment. The expanded depletion region induced by the plasma treatment made the whole contour of the depletion region near the gate electrode sufficiently enlarged to sustain a high reverse bias. The modification of the internal field and depletion contour was confirmed by an upward band bending in the simulated energy band structure (Fig. 3) [10].

As shown in Fig. 3(a), the gradient of the potential (energy band) of the plasma treated device is relatively shallow at the AlGaN and GaN region, whereas that of the conventional one is steep at both regions. According to the Poisson equation, the gentle gradient of the potential indicates that a low electric field is induced at both layers. As the slope of the potential at both regions become more gradual, the depth of the quantum well formed at interface becomes shallow. It is directly related to the decrease of the carrier density, as shown in Fig. 3(b). In addition, the expansion of the depletion region in the GaN is confirmed in the simulated band structure. The depletion which plays a significant role in the reverse operation mode is the one formed in the GaN buffer layer rather than that formed in the AlGaN layer. In AlGaN/GaN HEMTs, it is defined as the length from the interface and the plateau of the band. As shown in Fig. 3(a), the depletion depth of the proposed device is much deeper than that of a conventional HEMT without any reverse bias.

The change of the depletion was verified from the measured