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Improvement of Contacts on Etched p-type GaN by Low-bias ICP–RIE

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Abstract

We investigated the effect of ICP–RIE bias power (P_{bias}) on the electrical contacts on etched p-type GaN. The etching damage was evaluated using photoluminescence, and green luminescence was observed only in the etched samples. The *I–V* characteristics between two Ni/Au-based ohmic electrodes on the surface were also examined, and the sample etched under the low-bias condition (P_{bias} = 2.5 W) exhibited a good ohmic-like characteristic on a level with that of nonetched sample.

1. Introduction

Gallium nitride (GaN) is a promising material for application in high-power and high-frequency electronic devices. In particular, GaN-based npn-type heterojunction bipolar transistors (HBTs) are attracting attention for their power-handling capabilities and high-frequency characteristics [1]. Since GaN is chemically stable, dry etching, such as inductively coupled plasma–reactive ion etching (ICP–RIE) has usually been used for device fabrication. However, damage is induced during dry-etching processes, which seriously degrades the electrical properties of GaN. As a result, the performance of devices such as GaN-based HBTs, which require etching to expose the p-type GaN surface covered by epitaxial layers, is limited by this degradation [2]. To realize such electronic devices, a low-damage dry etching method for exposing the buried p-type GaN is highly desired.

Very recently, it has been reported that in n-type GaN, ICP–RIE with a low bias power could reduce the etching damage and improve the current–voltage characteristic of Schottky barrier diodes [3]. In this study, we applied the low-bias power ICP–RIE to Mg-doped p-type GaN, which exhibited a good ohmic-like characteristic similarly to that of the nonetched sample even after dry etching.

2. Experimental Method

We used a 1-µm-thick Mg-doped p-type GaN ([Mg] = 1×10^{19} cm^{-3}) grown by metal organic vapor phase epitaxy on a n-type free-standing GaN substrate. The entire surface of samples was etched to 300±10 nm by ICP–RIE under the following conditions. Chlorine was employed as the reactive gas (Cl_2; flow rate, 30 sccm) with the pressure kept at 2.0 Pa. The ICP power was maintained at 150 W, and the bias power (P_{bias}) was varied for each sample at 2.5, 5.0, 15 and 30 W within the error of ±0.3 W. The samples were annealed at 700 °C in nitrogen atmosphere for 5 min so as to activate the Mg acceptors, and the etching damage was evaluated using photoluminescence (PL). Then, Ni/Au-based ohmic electrodes were formed on the surface for electrical evaluations. Ni and Au were deposited by electron-beam evaporation and annealed at 525 °C in oxygen atmosphere for 5 min. Finally, the current–voltage (*I–V*) measurements were carried out to characterize the electrical contacts.

3. Results and Discussion

Fig. 1 shows the PL spectra of (a) as-grown and (b), (c)

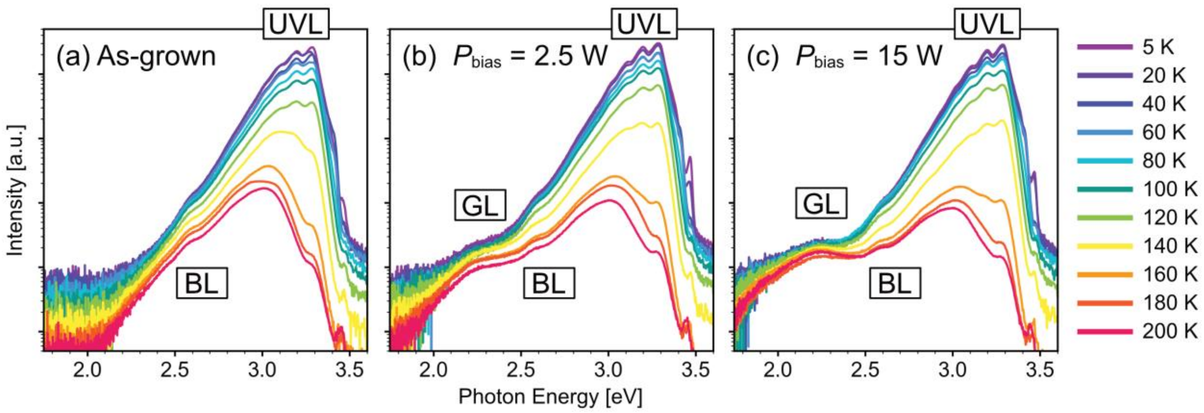

Fig. 1 PL spectra of (a) as-grown and (b), (c) etched p-type GaN ([Mg] = 1×10^{19} cm^{-3}). The P_{bias} values are (b) 2.5 and (c) 15.0 W. The measurement temperatures were ranging from 5 to 200 K.

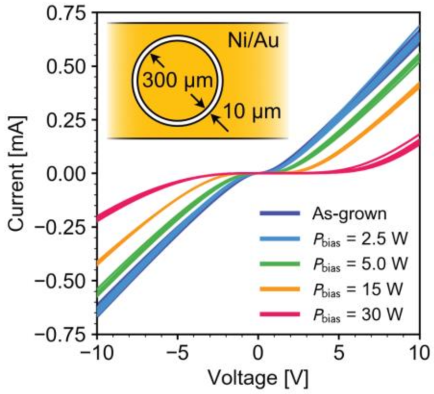

Fig. 2 *I–V* characteristics of Ni/Au with p-type GaN after various P_{bias} etchng. The inset shows the schematic of measured samples.

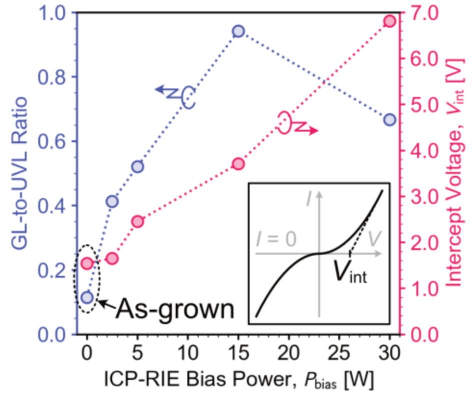

Fig. 3 GL-to-UVL ratio (left) and intercept voltage (right) as functions of P_{bias}. The inset shows the definition of V_{int} from an *I–V* curve.

etched samples measured at selected temperatures ranging from 5 to 200 K. Two or three sets of PL bands can be seen from each sample. The first set is the ultraviolet luminescence (UVL) band, which consists of the main peak at around 3.29 eV and its LO phonon replicas (3.20, 3.10 and 3.02 eV) originating from a shallow donor or the conduction-band minimum to a Mg acceptor substituted on a Ga site (Mg_{Ga}) transition [4]. The second set is the blue luminescence (BL) band with a peak at around 2.6 eV arising from a deep donor to a shallow Mg_{Ga} acceptor transition [4]. The final set is the green luminescence (GL) band having a maximum at around 2.2–2.3 eV. This GL can only be seen in the etched samples at moderate temperatures. Reshchikov *et al.* studied the origin of the GL in UID-GaN and Mg-doped GaN grown by molecular beam epitaxy under a Ga-rich condition, in which nitrogen vacancies (V_Ns) often exist, through both theoretical and experimental methods. Their conclusion was that the most probable candidate for the GL with a peak at 2.35 eV is the V_N-related emission [5]. Kato *et al.* investigated deep levels in n- and p-type GaN after ICP-RIE by using deep level transient spectroscopy (DLTS). They observed an increase in the concentration of a donor-type defect with an activation energy of 0.25 eV, which is labeled as “E1”, on the basis of capacitance DLTS measurements of etched n-type GaN, and concluded the origin to be V_Ns [6]. Therefore, taking into account the fact that a V_N has a low formation energy in p-type GaN [5], an ICP–RIE induced V_N is a plausible candidate for the origin of the GL.

The *I–V* characteristics of the annealed Ni/Au with p-type GaN after etching at various P_{bias} are summarized in Fig. 2. Although all samples show nonlinear curves, the ohmic characteristics are improved with decreasing P_{bias}, and almost the same *I–V* curve as that of the as-grown (nonetched) sample is obtained with P_{bias} of 2.5 W. In Fig. 3, the intercept voltage (V_{int}) which corresponds to the voltage drop in the damaged layers [7], and the GL-to-UVL ratio extracted from the PL result measured at 200 K are expressed as a function of P_{bias}. As shown, V_{int} decreases from 6.81 to 1.65 V with decreasing P_{bias} from 30 to 2.5 W. The tendency of a decreasing GL-to-UVL ratio with decreasing P_{bias} is also observed. This implies a decrease in the total number of V_Ns. Narita *et al.* studied the etching-induced surface damage in p-type GaN by hard X-ray photoelectron spectroscopy and revealed the existence of a high density of deep donors (> 1×10^{20} cm^{-3}) and an increase in the thickness of the damaged layer (5–8 nm) with increasing P_{bias} [8]. Therefore, a reduction in the total number of V_Ns, which act similarly to donors and compensate for holes, is the most probable reason for the improvement of the ohmic characteristics with decreasing P_{bias}.

4. Conclusions

We investigated the effect of P_{bias} on the damage induced by ICP–RIE. The etching damage was evaluated using PL, and the GL having a maximum at around 2.2–2.3 eV was observed only in the etched samples. The *I-V* characteristics of the two annealed Ni/Au electrodes were also examined. The non-ohmic behaviors in etched samples improved with decreasing P_{bias}, and good ohmic-like characteristics with V_{int} of 1.65 V, which is similarly to that of the nonetched sample, was exhibited at the P_{bias} of 2.5 W. On the basis of the GL-to-UVL ratio obtained from the PL result, the probable reason for such improvement was thought to be the reduction in the total number of V_Ns by decreasing P_{bias}. It is thus concluded that ICP–RIE with a low P_{bias} is an effective etching method for the exposure of buried p-type GaN.

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