n형 GaN의 doping 농도에 따르는 건식 식각 손상

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Doping-level dependent dry-etch damage of in n-type GaN

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Abstract

The electrical effects of dry-etch on *n*-type GaN by an inductively coupled $Cl_2/CH_4/H_2/Ar$ plasma were investigated as a function of ion energy, by means of ohmic and Schottky metallization method. The specific contact resistivity (ρc) of ohmic contact was decreased, while the leakage current in Schottky diode was increased with increasing ion energy due to the preferential sputtering of nitrogen. At a higher rf power, an additional effect of damage was found on the etched sample, which was sensitive to the dopant concentration in terms of the ρc of ohmic contact. This was attributed to the effects such as the formation of deep acceptor as well as the electron-enriched surface layer within the depletion layer. Furthermore, thermal annealing process enhanced the ohmic and Schottky property of heavily damaged surface.

Key Words : damage, dry-etch, GaN, doping

1. 서 론

During the last decade, varieties of etching methods for reliable pattern transfer of GaN have been reported, and a dry etching method has proven to be effective for the fabrication of light emitting diodes (LED) and laser diodes [1-3]. However, energetic ion bombardment -induced damage, which accompanies the dry etch process can lead to deterioration in the optical and electrical properties of the semiconductors [4-7]. The specific contact resistivity (ρ_c) and current-voltage (I-V) measurement extracted from the ohmic contact and Schottky diodes, respectively, have been found to be very sensitive to the surface damage induced by dry-etching of semiconductors [8]. It is well known that the depth of damaged surface, etched with chemical component, should be smaller than those etched with physical component [9] Thus, it is also expected that the contact behavior of the surface etched with chemical component is different from those etched with physical component since ρ_c depends on the semiconductor doping concentration as well as the depth of the interfacial layer, formed by dry-etch between metal and semiconductor [10]. In this article, we report on the effects produced by inductively coupled $Cl_2/CH_4/H_2/Ar$ plasma (ICP) on *n*-type GaN surfaces, exploiting an ohmic and Schottky metallization method.

2. 실 험

Two types of Si-doped GaN films with thickness of 1.5 ㎛, were grown on a c-plane sapphire substrate using a metalorganic chemical vapor deposition method by controlling the flow rate of SiH_4 as an *n*-type dopant source. The carrier concentration was assessed by the Hall measurement. The etching of GaN was performed under $Cl_2/CH_4/H_2/Ar$ (30/8/8/16 sccm) plasmas, at different rf condition. The ρ_c was measured using a Ti (30 nm) as an ohmic metal by a transmission line method, and currents -voltage (I-V) curve were extracted from the Schottky diodes, which were fabricated using an Ti/Au (30/80 nm) and Ni/Au (30/80 nm) as ohmic and Schottky metals, respectively. A PL measurement at 10 K was performed in order to investigate the optical properties of the etched film using a He-Cd laser (325 nm). RTA were also performed under N_2-ambient for 1 min to evaluate the thermal stability of the etch-damage in Schottky diodes.

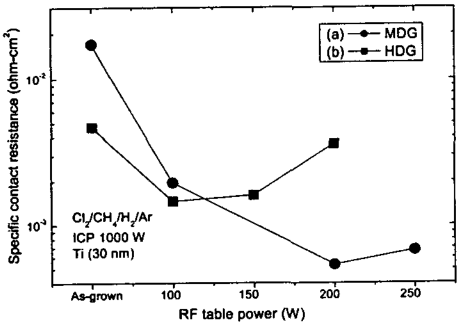

Fig. 1 Specific contact resistivity (ρ_c) as a function of rf table power using as-deposited Ti on surfaces of (a) MDG and (b) HDG.

3. 결과 및 고찰

Figure 1 shows the ρ_c as a function of rf table power on the surfaces of (a) moderately-doped (n = 1 × 10^{18} cm^{-3}; MDG), (b) more highly-doped (n = 5 × 10^{18} cm^{-3}; HDG), and (c) N_2-plasma treated (NPT) GaN after the dry etching of HDG. The contact resistance (R_s) does not change, in accordance with the result of Thomas *et al.*[8]. The HDG sample shows a lower ρ_c than that of the MDG sample under as-grown state due to the increase of the tunneling mechanism. It is well known that the ρ_c of a dry-etched surface decreases due to the nitrogen vacancies on the GaN surface which act as shallow donors [9]. The samples etched at 100 W of table power show a lower ρ_c than those of the as-grown samples regardless of the carrier concentration, and correspondingly a monotonic decrease in the ρ_c for a MDG sample was observed as the rf power increased up to 200 W (induced dc-bias of 220 V), resulting in 5.34 × 10^{-4} Ωcm^2. This means that the degree of plasma damage, assumed to be a nitrogen vacancy, is enhanced, due to the severity of nitrogen loss at a higher rf power. However, a further increase in the rf table power of 250 W for MDG sample caused the ρ_c to increase, as can be seen in Fig. 1 (a). Pearton *et al.*[11] have reported that if the system undergoes energetic ion bombardments, then electrical compensation could occur by forming deep acceptor states. It is evident that the additional damage which compensates the Si-donor dominate the ρ_c an rf table power above 200 W. For an HDG sample, a similar behavior was observed. Figure 1 (b) shows the initial decrease in ρ_c down to 1× 10^{-3} Ωcm^2 and increase subsequently as the rf power is increased over 100 W. Note that the threshold rf power for the introduction of additional damage is much smaller for the HDG than those for MDG, indicating that the highly doped GaN is more vulnerable to the introduction of such additional damages. It was known that highly doped layers are quite resistant to plasma-induced damage such as the introduction of deep acceptor state because it is difficult to produce sufficient number of deep levels to affect the layer conductivity [11]. However, the presence of the electron-enriched surface layer within the depletion layer may change the transport property of etched surface. Popovic [10] proposed that ρ_c is gradually decreased with increasing the depth of the electron-enriched surface layer (X_n) due to the reduction of barrier height. When the X_n is greater than the width of the depletion region (W_n), *i. e.* $W_n \leqq X_n$, however, the ρ_c should not be influenced by the electron-enriched surface layer. From this result, the threshold rf power in Fig. 1 is the very condition that W_n is equal to X_n. Thus, the threshold rf power of HDG sample is lower than that of the MDG sample since the W_n is inversely proportional to the donor concentration. This result clearly shows that the additional damage by dry etching will be formed, though the chemical components present in the plasma.

PL measurements were performed at 10 K. In Fig. 2, the dominant transition line at 356.5 nm (3.47eV), the I_2 line, is due to the recombination of the excitons bound to donors [13.] In our PL results, however, the additional transition [14] was not observed, indicating that the shallow donors by nitrogen vacancies are restricted on the topmost surface due to less contribution to the luminescence of surface than that of the bulk, in accordance with the R_s value. On the other hand, the PL intensity of I_2 peak decreased with increasing the rf power, as shown in Figs. 2 (a), (b), and (c). At an rf power of 200 W, the PL intensity drastically decreased by 4 orders of magnitude of PL intensity of the as-grown sample. These results also confirm that the HDG sample etched at a higher rf power suffer from other kind of damage, which is different from those for etched at a lower rf power.

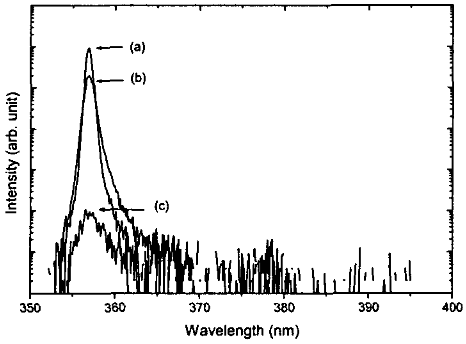

Fig. 2 PL spectra of HDG samples at 10 K taken from (a) as-grown, (b) etched HDG at 100 W of rf table power, (c) etched HDG at 200 W of rf table power

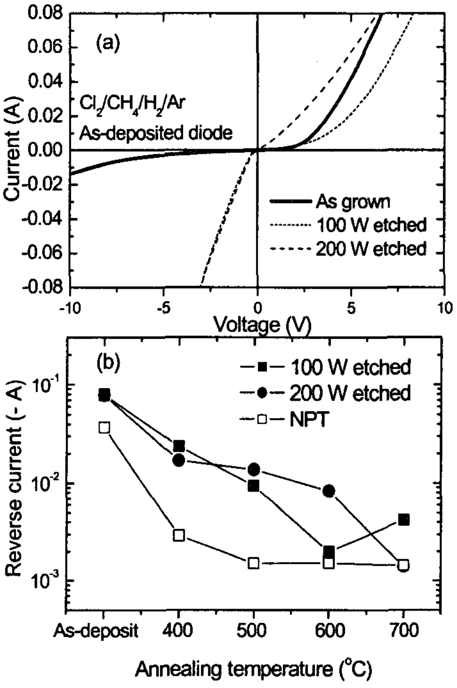

Fig. 3 (a) I-V characteristics of Schottky diode on HDG sample at an as-deposit state as a function of rf table power, and (b) Reverse current variation with annealing temperature measured at a bias of 3 V. NPT sample was etched at 200 W of rf power prior to N_2-plasma treatment.

One of the sensitive methods to evaluate damage is to investigate the diodes characteristics of Schottky contacts. Figure 3 (a) shows the typical I-V characteristics of Schottky diode on HDG sample. The diodes become leaky when the sample was etched at 100 W and 200 W rf power due to the collective effects of etch-induced damages [9].

We also investigate the RTA effects on the reverse currents of Schottky diodes, as shown in Fig. 3 (b). The annealing process of the as-grown sample did not show any noticeable change in the I-V characteristics of the Schottky contact up to 600 ℃, indicating that there wasn't any metallurgical interaction between metal and GaN. The reverse currents of 100 W etched sample shows the linear decrease up to temperatures of 600 ℃, while those of 200 W shows the non-linear recovery mechanism, indicating that the full recovery of the etch-induced damage require higher temperature than those for 100 W etched sample such as 700 ℃ in this experiment. However, NPT sample shows faster decrease in leakage current than those of the etched samples. From these results, we conclude that the NPT lowers the activation energy for the recovery of etch-damage.

4. 결 론

In summary, we have studied the ion - bombardment effect on the electrical properties of n-type GaN using and ohmic and Schottky metallization method under real device process condition. Additional effects of damage were found on the etched GaN sample at a higher rf power, which is more sensitive to the doping concentration in terms of the specific contact resistivity in ohmic contact. In addition, the N_2 plasma treatment on the etched GaN surface along with RTA process enhanced the ohmic and Schottky property of heavily damaged surface.

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