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A study of GaN etch mechanisms using inductively coupled Cl_2/Ar plasmas

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Abstract

GaN etching was performed using planar inductively coupled Cl_2/Ar plasmas, and the effects of main process parameters on the characteristics of the plasmas and their relations to GaN etch rates were studied. GaN etch rates increased with the increase of chlorine radical density and ion energy, and a vertical etch profile having an etch rate close to 400 nm/min could be obtained. The GaN etch rate appeared to be more affected by the chemical reaction between Cl radicals and GaN compared to the physical sputtering itself. This GaN etch mechanism was studied using Langmuir probe and optical emission spectroscopy (OES) during etching, and X-ray photoelectron spectroscopy (XPS) of the etched surfaces. © 1999 Elsevier Science S.A. All rights reserved.

Keywords: GaN; Plasma etching

1. Introduction

Group III-nitride semiconductors such as GaN have great potential for the fabrication of optoelectronic devices such as light-emitting diodes and laser diodes, and electronic devices operating at high temperatures. However, to fabricate GaN-based optoelectronic devices successfully [1,2], reproducible etching processes with high etch rate and vertical etch profile are required. Recently, dry etching techniques using high density electron cyclotron resonance (ECR) plasmas or chemically assisted ion beams have been employed to define device features with controlled profiles and etch depths [3–8]. While most studies on dry etching are focused on the etch properties related to the etch equipment and etch process parameters such as plasma chemistry, source power, bias voltage, etc., detailed studies on the dry etching characteristics of GaN-based materials based on the plasma diagnostic and surface analysis have been little reported. In this study, the plasma characteristics and GaN etch properties of inductively coupled Cl_2/Ar plasmas were investigated.

2. Experimental

A 2 μm thick GaN epitaxial layer was grown by MOCVD on a (0001) sapphire wafer and sputtered SiO_2 was used as a mask layer. To generate inductively coupled plasmas, 13.56 MHz r.f. power was applied to the planar spiral Cu coil above the 1 cm thick quartz window located on the top of the process chamber. Separate 13.56 MHz r.f. power was also applied to the bottom electrode to generate d.c. self-bias voltages measured using a high voltage probe (Tektronix P6015A). Inductive power was varied from 200 to 600 W, d.c. self-bias voltage from 0 to − 120 V, and substrate temperature from 3 to 70°C. Gas combination of Cl_2/Ar was used to etch GaN while the operating pressure was kept at 1.4 Pa. A single Langmuir probe was inserted in the center of the chamber to estimate ion densities of the plasmas and was biased at − 40 V to collect ion currents. Because it is difficult to measure ion density for molecular gases, the ion current density was used as a measure of ion density. During the etch processes, optical emission spectroscopy (OES, SC Tech. PCM402) was used to monitor dissociated radicals and etch products such as Ga, N, and $GaCl_x$ in the plasmas. Optical emission peaks were measured from the sidewall viewport of the chamber using a fused silica lens focused on the GaN surface. Surface composition of the etched GaN was analyzed using angle-resolved X-ray photoelectron spectroscopy (XPS, Fisons Instruments

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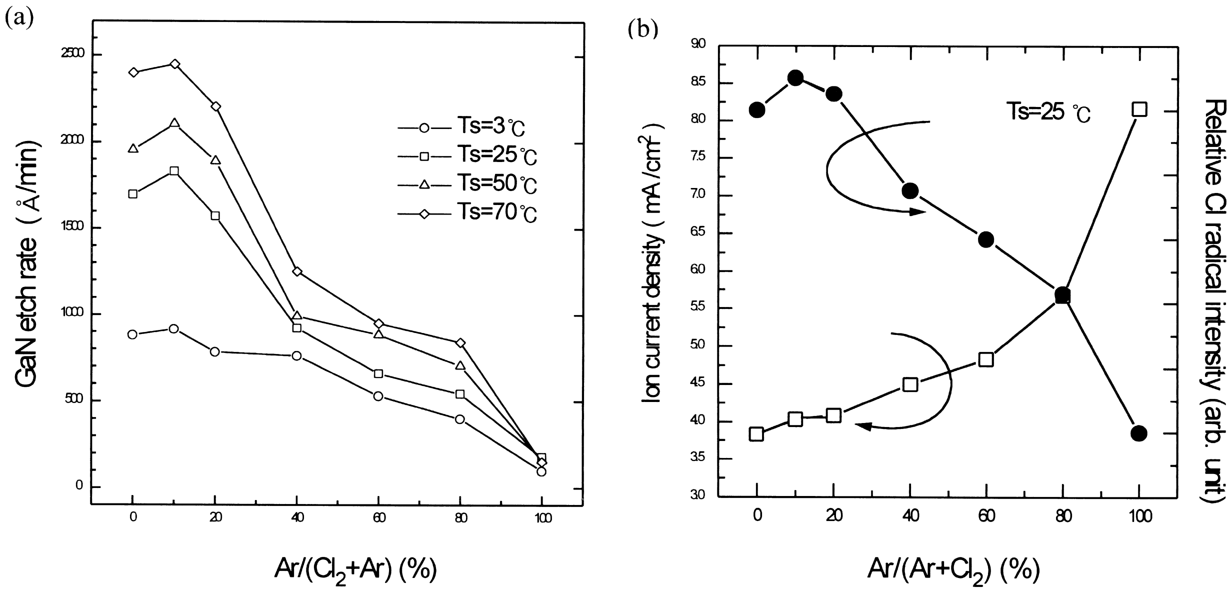

Fig. 1. (a) GaN etch rate as a function of Cl_2/Ar gas ratio at substrate temperatures from 3°C to 70°C, and (b) ion current density and relative Cl radical intensity in the Cl_2/Ar plasmas at the substrate temperature of 25°C, 400 W inductive power, and − 120 V bias voltage.

Surface Systems ESCALAB 220i) before and after the plasma etching.

3. Results and discussion

GaN etch rates increased with inductive power possibly due to the increase of ion current density and the reactive Cl radical in the plasma. As the d.c. bias voltage increased from 0 to − 120 V at fixed inductive power, the GaN etch rate also increased. The enhancement of the GaN etch rates by the increase of bias voltage was ascribed to the increased energetic ion bombardment because the changes of the ion density and Cl radical with bias voltage were negligible (not shown).

To investigate the effects of gas combination of Cl_2/Ar on the etch rate of GaN, etching was performed at a fixed pressure of 1.4 Pa, 400 W inductive power, and − 120 V d.c. self-bias voltage. Fig. 1 shows the effects of Ar addition on GaN etch rates (a) and on ion current density and Cl radical density (b). As shown in Fig. 1a, the addition of more than 20% Ar decreased GaN etch rates, however, the

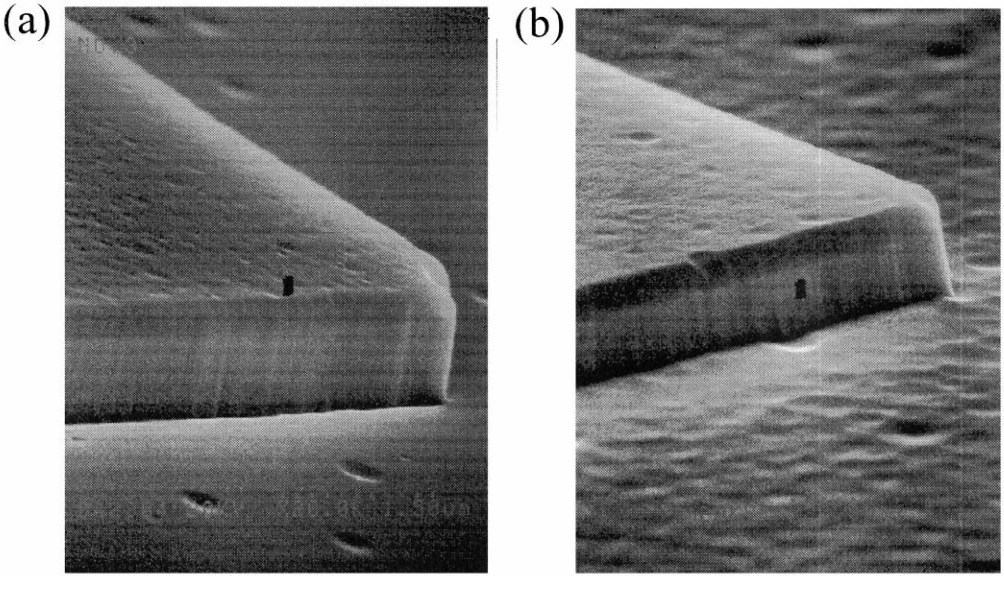

Fig. 2. SEM micrographs of SiO_2/GaN/sapphire etched using (a) 100% Cl_2 plasma and (b) 80%Cl_2/20%Ar plasma at the substrate temperature of 70°C, 600 W inductive power, and − 120 V bias voltage.

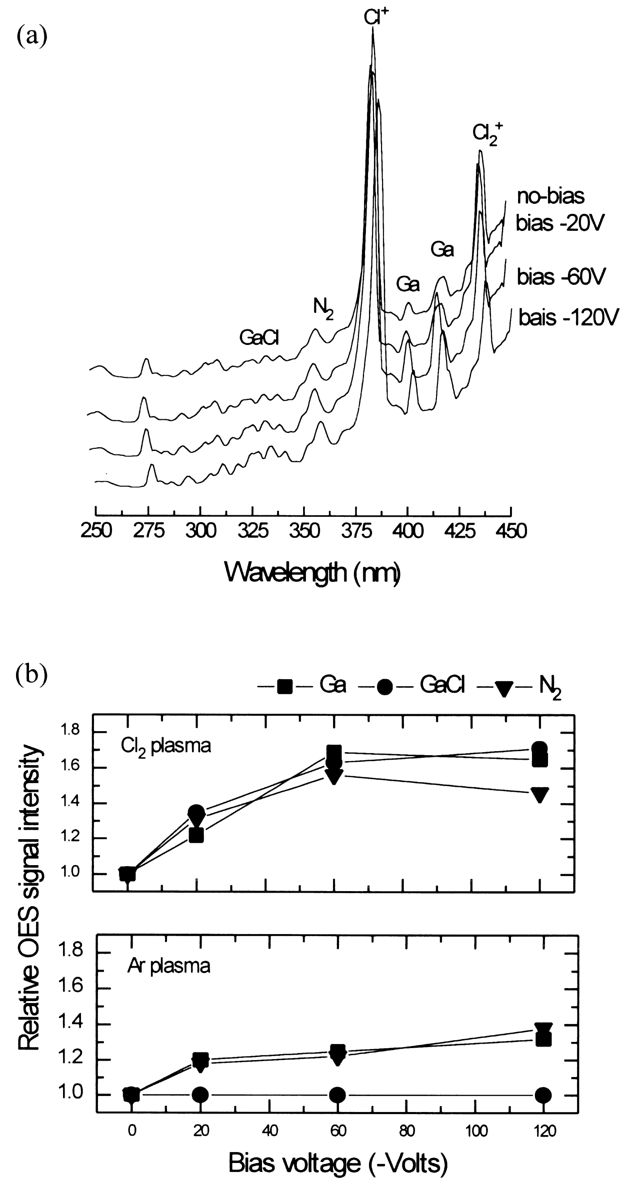

Fig. 3. (a) Optical emission spectra as a function of bias voltage during the GaN etching by 100% Cl_2 plasmas and (b) the relative optical emission intensities at the temperature of 25°C and 400 W inductive power.

addition of a small amount of Ar, near 10%, increased GaN etch rates slightly. The addition of Ar to Cl_2 plasmas increased ion densities monotonically as shown in Fig. 1b. In the case of Cl radical density, it showed a similar trend as that of GaN etch rates. The addition of a small amount of Ar can enhance the removal of etch products such as $GaCl_x$ by physical sputter etching, however, the change of GaN etch rates near 10% Ar appears to be more closely related to the change of Cl radicals as shown in Fig. 1b. Therefore, to obtain high GaN etch rates, not only sputter etching by energetic ion bombardment is required to break the strong chemical bonding of GaN but also chemical reaction forming volatile etching products is required in GaN etching.[6,8] The importance of chemical reaction in GaN etching can be also understood from the enhancement of GaN etch rates as a function of substrate temperature as shown in Fig. 1a. For the 100% Cl_2 plasmas, GaN etch rates increased more with the increase of substrate temperature compared to those for the 100% Ar plasmas. As a result, GaN etch rates close to 4000 Å/min with anisotropic etch profiles could be obtained at 600 W inductive power, − 120 V bias voltage and 70°C substrate temperature in various Cl_2/Ar gas combinations. Some etch profiles etched using Cl_2/Ar plasmas are shown in Fig. 2. As shown in Fig. 2, the addition and increase of Ar in Cl_2 generally reduced the etch anisotropy.

To investigate the interaction between plasma and GaN, etch products during the GaN etching were monitored using OES while etching 2 inch blank GaN/sapphire wafers. Some of the emission spectra during the GaN etching using 100% Cl_2 plasmas are shown in Fig. 3a as a function of bias voltage. These optical emission peaks were confirmed from the separate measurement of $GaCl_x$ and Ga peaks during the GaAs etching in Cl_2 plasmas and from N_2 peaks in N_2 plasmas. The emission peaks from etch products such as Ga (402 nm), $GaCl_x$ (337 nm), and N_2 (358 nm) were monitored. The measured emission intensities of $GaCl_x$ increased with the increase of inductive power, bias voltage, and substrate temperature. Fig. 3b shows the relative optical emission intensities of the species as a function of bias voltage during the GaN etching using pure Cl_2 and Ar plasmas. The emission signals were normalized to the respective signals from no-bias conditions. As shown in Fig. 3, the increase of optical emission intensities as a function of bias voltage was much higher for the Cl_2 plasmas compared to that for the Ar plasmas. Because the Ar plasmas contain more ion density and less Cl radical density compared to the Cl_2 plasmas as shown in Fig. 1b, the increase of the etch products is possibly related to the increased chemical reactions between Cl and Ga in GaN due to the increased GaN reactivity by the high ion energy bombardment.

The increased chemical reaction between Cl and GaN can preferentially remove a component from the GaN surface during the etching. Therefore, angle resolved XPS analysis was carried out to analyze the variation in Ga/N ratio of the etched GaN surface. The take-off angle was varied from 30° to 90°. The higher take-off angle represents the detection of XPS signals from the deeper position of the etched GaN surface. As shown in Fig. 4, as it gets closer to the surface, nitrogen-rich GaN is obtained and the GaN surface etched by 100% Cl_2 shows the most nitrogen-rich surface; the addition of Ar improved the stoichiometry of the surface, which shows the preferential removal of Ga from the GaN surface by the reaction of Cl and Ga in GaN under ion bombardment conditions enough to break GaN bonds. The deviation from stoichiometry could affect the resistance of the ohmic contact which is formed on the etched GaN surface [9].

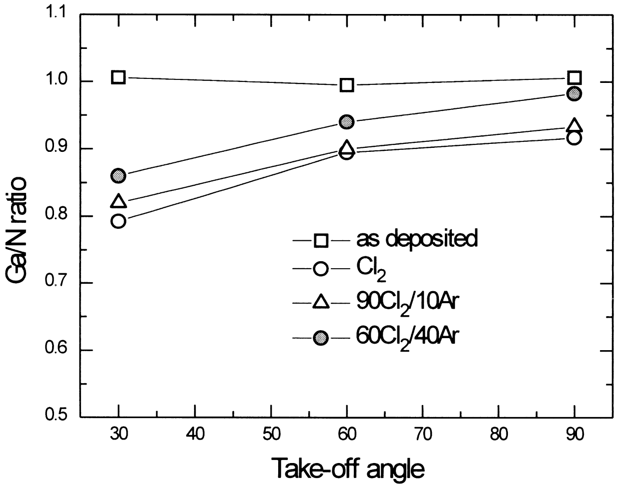

Fig. 4. The variation in Ga/N ratio of the GaN surface, measured by angle resolved XPS, etched at 600 W inductive power, − 120 V bias voltage, and 25°C substrate temperature.

4. Conclusions

Planar inductively coupled Cl_2/Ar plasmas were used to characterize GaN etch properties and the effects of process parameters such as gas combination, inductive r.f. power, d.c. self-bias voltage, and substrate temperature on the etch properties of GaN and their relations to the characteristics of the plasmas were studied. Using inductively coupled Cl_2/Ar plasmas, etch rates close to 4000 Å/min with anisotropic etch profiles could be obtained without substrate heating over 100°C or biasing over − 120 V used generally by other groups. GaN etch rate appeared to be more affected by the chemical reaction between Cl radical and GaN compared to the physical sputtering itself, as was confirmed by some plasma diagnostics using Langmuir probe and OES during the etching and by XPS analysis of the etched GaN surface.

Acknowledgements

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References

[1] J.C. Zolper, R.J. Shul, MRS Bull. (1997) 36.
[2] S. Nakamura, M. Senoh, S.I. Nagahama, N. Iwasa, T. Yamada, T. Matsushita, H. Kiyoku, Y. Sugimoto, Jpn. J. Appl. Phys. 35 (1996) L74.
[3] C.B. Vartuli, S.J. Pearton, C.R. Abernathy, R.J. Shul, A.J. Howard, S.P. Kilcoyne, J.E. Parmeter, M. Hagerott-Crawford, J. Vac. Sci. Technol. A 14 (1996) 1011.
[4] S.J. Pearton, C.B. Vartuli, R.J. Shul, J.C. Zolper, Mater. Sci. Eng. B31 (1995) 1.
[5] R.J. Shul, G.B. McClellan, S.J. Pearton, C.R. Abernathy, C. Constantine, C. Barratt, Electron. Lett. 32 (1996) 1408.
[6] I. Adesia, A.T. Ping, C. Youtsey, T. Dow, M. Khan, D.T. Olson, J.N. Kuznia, Appl. Phys. Lett. 65 (1994) 889.
[7] R.J. Shul, C.I.H. Ashby, D.J. Rieger, A.J. Howard, S.J. Pearton, C.R. Abernathy, C.B. Vartuli, P.A. Barnes, P. Davis, Mater. Res. Soc. Symp. Proc. 395 (1996) 751.
[8] C.B. Vartuli, J.D. MacKenzie, J.W. Lee, C.R. Abernathy, S.J. Pearton, R.J. Shul, J. Appl. Phys. 80 (1996) 3705.
[9] H.S. Kim, Y.H. Lee, G.Y. Yeom, J.W. Lee, T.I. Kim, Mater. Sci. Eng. B50 (1997) 80.